Geologic Setting and Trace Metal Chemistry of the Arapien Shale and Twist Gulch Formation, Central Utah

by

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ABSTRACT

The Arapien Shale and Twist Gulch Formation of Jurassic age were studied as possible future sources of economic concentrations of base- and precious-metals. Copper, lead, zinc, and silver contents were determined by atomic absorption spectrophotometry. Lead and zinc are slightly enriched when compared to other shales and mean crustal abundances, whereas copper concentrations were slightly lower. Silver was not detected in any of the samples.

Two types of metal enrichment were found: 1) a syngenetic (sabkha-type) copper enrichment expressed as interstitially deposited metal sulfides, and; 2) an epigenetic enrichment as veinlets and disseminations of chalcocite, malachite, and azurite. The latter mineralization perhaps is related to normal faulting in the area studied.

The importance of the Arapien Shale and Twist Gulch Formation as a future source of metals may lie with the syngenetically enriched segments associated with evaporite beds. This association may represent a Jurassic sabkha environment. The association encountered in the present study does not contain economic concentrations of copper. However, it may indicate that larger associations may be present in these formations.

CONTENTS

INTRODUCTION

The purpose of the present study was to determine the trace metal chemistry of the Arapien Shale and the Twist Gulch Formation, both of Jurassic age, and to evaluate the potential of these formations as possible future sources of base- and precious-metals.

The areas studied are in the southern Sanpete Valley and the eastern Sevier Valley, located respectively in Sanpete and Sevier counties, Utah (Figure 1).

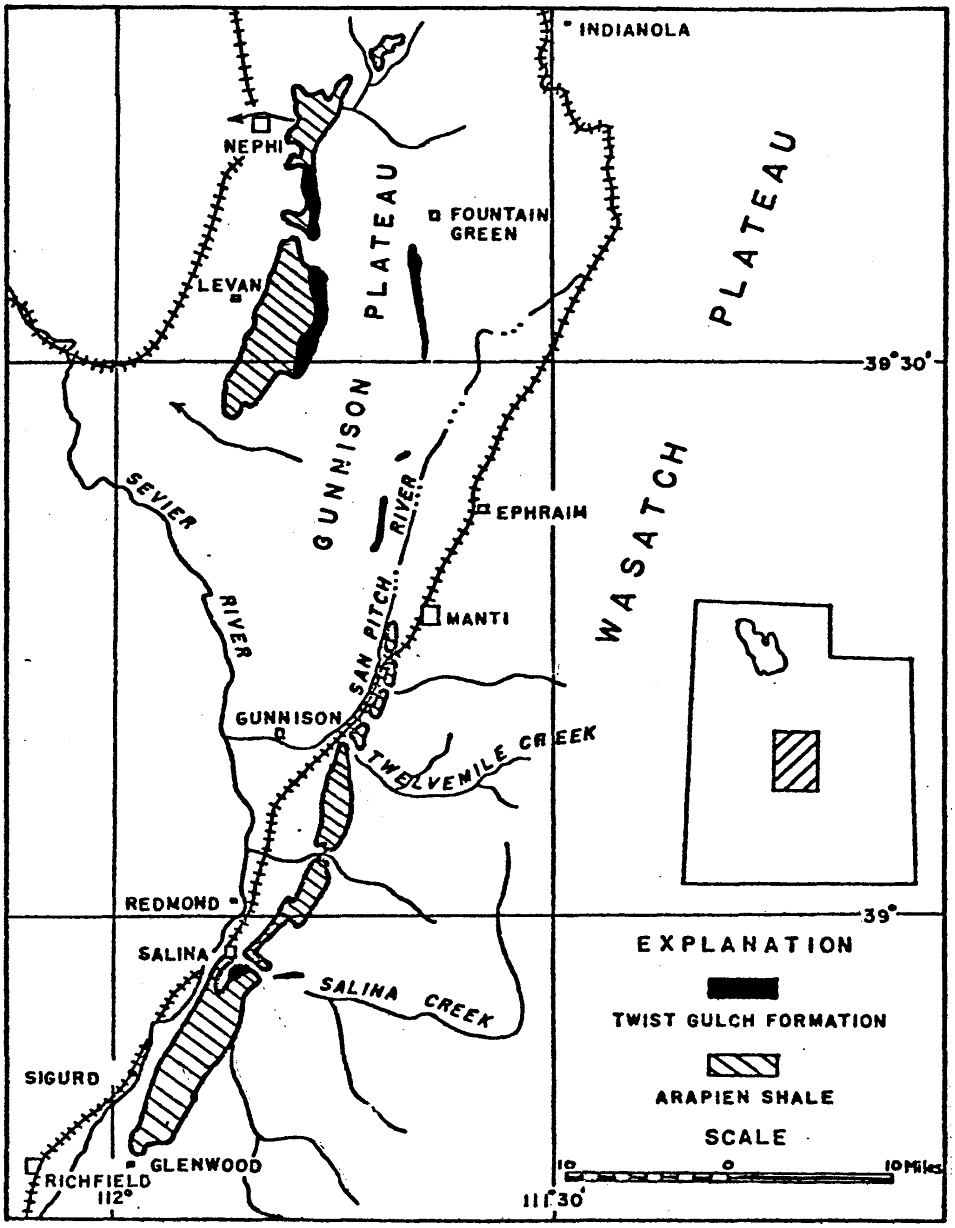


Figure 1. Index Map of Central Utah
(Modified from Hardy, 1952)

REGIONAL GEOLOGY

The study areas are bordered by the Sevier and Gunnison Plateaus to the west and the Wasatch Plateau to the east. Bedrock formations exposed in the area range from the Arapien Shale of Jurassic age to the Axtell Formation of Pliocene or Pliestocene age. These relationships are shown in Figure 2 (Spieker, 1946) and in Table 1 (Hardy, 1949). The Navajo Sandstone also was encountered at depth in the Standard Oil Company of California well, Sigurd Unit No. 1, located in Sec. 32, T. 22 S., R. 1 W., Sevier County, Utah (Gilliand, 1963).

Stratigraphy

The Navajo Sandstone, Arapien Shale, Twist Gulch Formation, and Morrison (?) Formation, all of Jurassic age,and the upper Cretaceous Indianola Group are overlain unconformably by the Price River Formation also of upper Cretaceous age (Spieker, 1946). The North Horn Formation of upper Cretaceous to Paleocene age lies conformably on the Price River Formation. These formations are overlain conformably by the Flagstaff Limestone, and the Colton, Green River, and Crazy Hollow formations, all of Eocene age. The section is capped by pyroclastic rocks, lava flows, and the Axtell Formation. The Axtell Formation

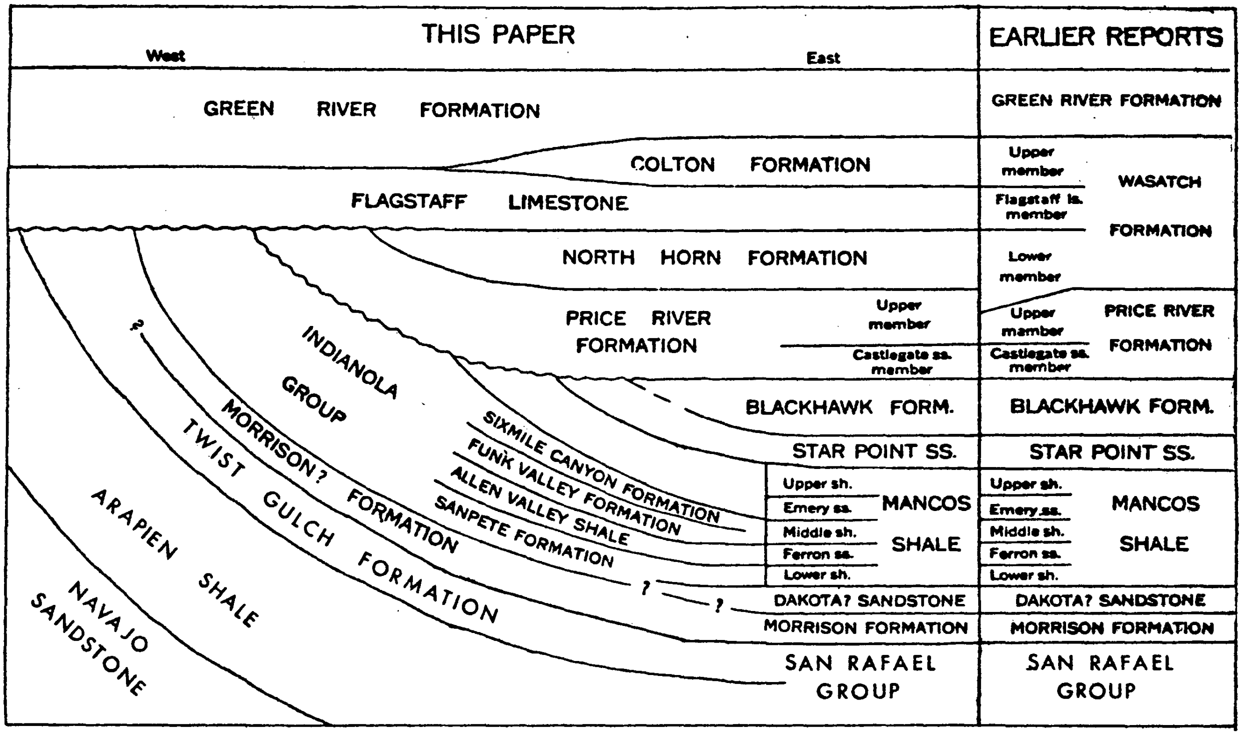


Figure 2. (Modified from Spieker, 1946)

Table 1 (Modified from Hardy, 1949).

AGE		FORMATION	CHARACTER	THICKNESS (Feet)
TERTIARY		Axtell	Conglomerate, gravel	Unknown
		Unconformity		
		Lava flows	Trachyte and related rocks	0-500+
		Unconformity		
		Pyroclastic rocks	Gray sandstone, buff limestone, shale, bentonite, volcanic ash	0-700+
		Unconformity		
	Eocene	Crazy Hollow	Gray sandstone, red shale	0-600+
		Green River	Green-gray shale, buff limestone	0-800+
		Colton	Red and green-gray shale	0-300+
	Paleocene(?)	Flagstaff	Gray limestone and shale, red siltstone, conglomerate	0-800+
		Local Unconformity		
	Paleocene	North Horn	Not present in mapped area.	
CRETACEOUS	Upper Cretaceous	Price River	Not present in mapped area.	
		Unconformity		
		Indianola group	Brown sandstone, conglomerate	7,000+
JURASSIC	Upper Jurassic	Morrison (?)	Conglomerate, gray sandstone variegated shale, limestone	300-1,000
		Twist Gulch	Red siltstone, reddish-gray sandstone	3,000
		Arapien Shale	Gray-to-red sandstone and shale	5,000-7,000
		Navajo Sandstone	Buff aeolian sandstone	Unknown

overlaps most of the older units and is composed largely of locally derived material, including debris from the lava flows (Hardy, 1949).

Structure

The area studied is dominated by three major structural features: the Sevier-Sanpete Valley anticline; the east Gunnison-Sevier fault system; and the Wasatch monocline (Gilliand, 1963). As described by Hardy (1949), the Sevier and Sanpete Valleys occupy a structural trough trending north-northeast. Perhaps the major structural feature of the area is the Sevier-Sanpete Valley anticline, a very large northerly-plunging anticline 65 to 70 miles long, with a structural relief of possibly as much as 15,000 to 20,000 feet (Figures 3 and 4). The anticline is 25 to 30 miles east of and parallel to the eastern limit of mid-Cretaceous folding in Utah. It lies in the middle of the orogenic belt transitional between the Colorado Plateau and the Great Basin (Gilliand, 1963).

The time of folding was no later than early Laramide. Hunt (1950) suggested that the Arapien Shale acted as a lubricating agent in an extensive decollement structure. The initial folding was followed by a period of less intense folding in the mid-Cretaceous (Spieker, 1930).

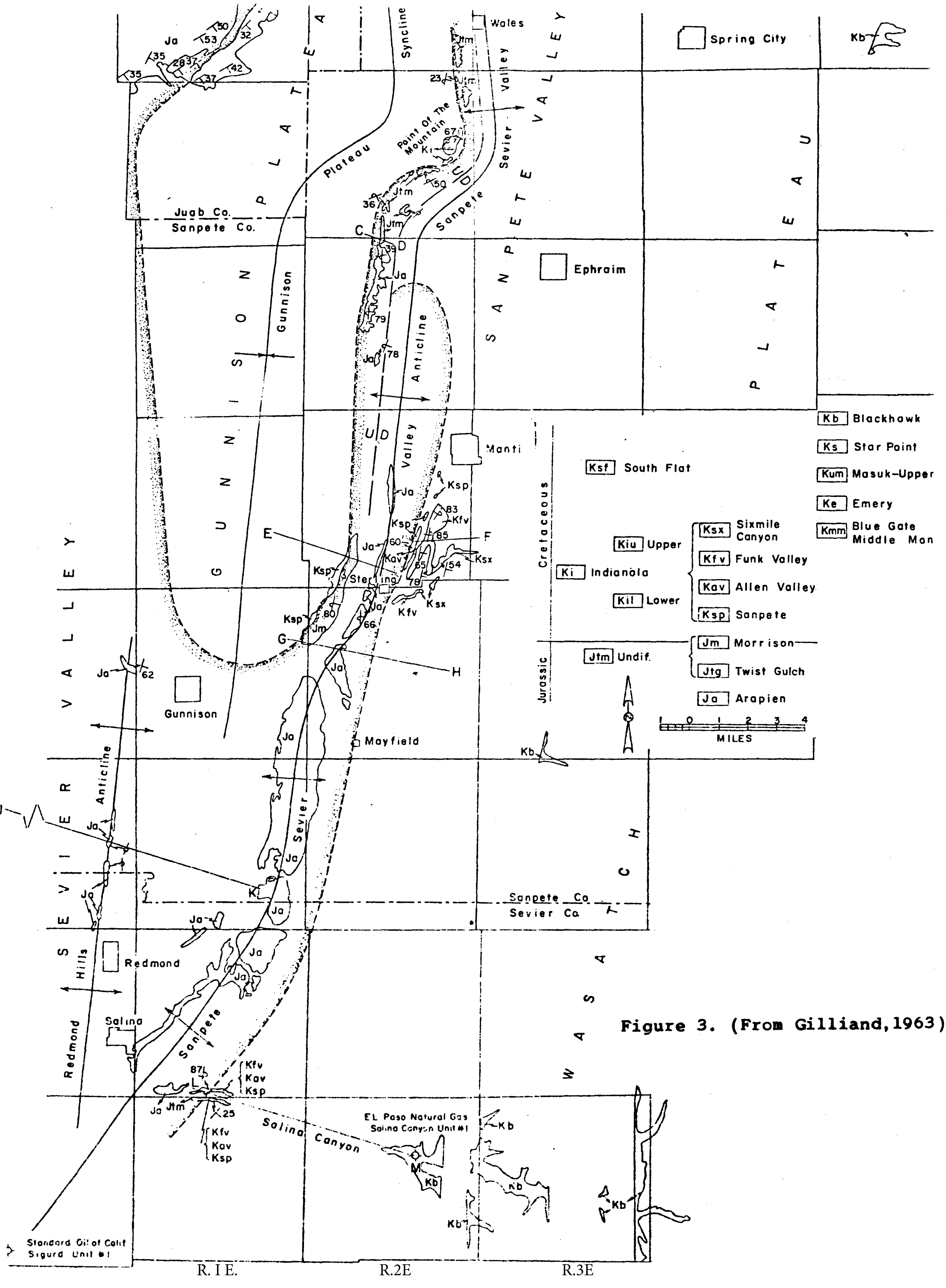


Figure 3. (From Gilliand,1963)

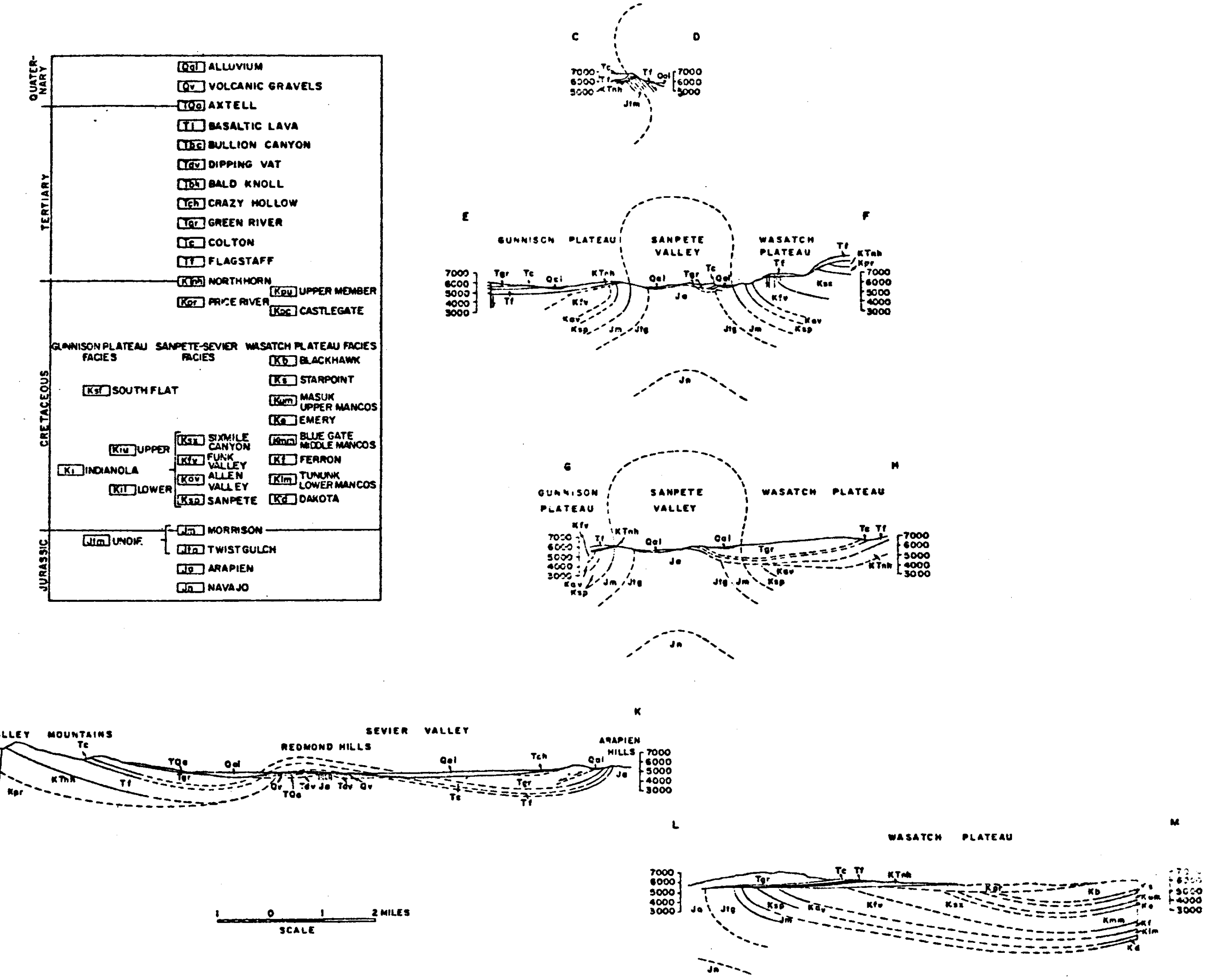


Figure 4. Structure Sections of the Sevier-Sanpete Valley Anticline (Modified from Gilliand, 1963)

In the southern Sanpete Valley the anticline is broken by a thrust fault with at least 5,000 feet of displacement to the east (Spieker, 1949).

The next major structural event occured in the Paleocene when normal faulting, eastern block downthrown relative to the western block, produced the Gunnison Plateau (Spieker, 1949). The normal faulting was followed by the folding and faulting of the Wasatch Monocline in late Eocene to Miocene time(Spieker, 1930). Hardy (1949) noticed that this was followed by a period of renewed normal faulting, possibly Recent in age.

THE STRATIGRAPHY, DISTRIBUTION, AND GENERAL STRATIGRAPHIC RELATIONSHIPS OF THE ARAPIEN SHALE AND TWIST GULCH FORMATION

The Arapien Shale was defined by E. M. Spieker in 1946. The unit consists largely of red-to-gray marine shales, fine-grained sandstones, and evaporite beds. Spieker first divided the Arapien Shale into two members, the Twelve Mile Canyon member and the Twist Gulch member. Five lithologic types were found within these members. They are: 1) a generally thin-bedded gray limestone; 2) very thin-bedded, light gray siltstone and shale with occasional thin beds of finely rippled sndstone; 3) gray argillaceous and gypsiferous shale, with irregular, locally abundant, red blotches; 4) compact red salt-bearing shale; and 5) thin-bedded red siltstone and shale with occasional zones of gray sandstone, and numerous thin layers of greenish white siltstone. Type 5 is the Twist Gulch member, and the Twelve Mile Canyon member is composed of types 1 through 4 (Spieker, 1946).

In 1949, Hardy and Spieker (Hardy, 1949) restricted the Arapien Shale to the Twelve Mile Canyon member, and they designated the Twist Gulch member as a separate formation. Hardy (1949) recognized five separate units within the Arapien Shale, exclusive of the Twist Gulch Formation, and these units are still in use. They are:

Unit E- Brick-red silty shale, locally salt-bearing. The salt appears stratified and commonly contains considerable red clay.

Unit D- Alternating layers of bluish-gray and red gypsiferous shale. The lenticular nature of the beds produces a blotchy appearance.

Unit C- Bluish-gray calcareous shale and gray, thin-bedded, calcareous sandstone. The unit contains several prominent resistant layers of arenaceous fossil-bearing limestone. Massive lenticular beds of gypsum also are present.

Unit B- Bluish-gray and red gypsiferous shale. The red gypsiferous shales are in the upper part, and locally are salt-bearing.

Unit A- Gray shale, gray thin-bedded brown-weathering limestone, red shale, thin lenticular bedded gypsum, and gray thin-bedded argillaceous limestone with massive lenticular beds of gypsum.

The Twist Gulch Formation is exposed on the north side of Salina Canyon (Figure 7) above Twist Gulch and is situated between the compact red, salt-bearing shale of Twist Gulch and the diverse strata of the Morrison (?) Formation (Spieker, 1949).

The general stratigraphic relationships of the Arapien

Shale and the Twist Gulch Formation are shown in figure 5. Spieker (1949) suggested that the Arapien Shale overlies the Navajo Sandstone, and this assumption later was substantiated by Gilliand (1963). Because of the complex structure of the area and the incompetent nature of the Arapien Shale, the units described by Hardy (1949) are not recognized in the same succession in all places. For a more detailed discussion of the interrelationships of these units, the reader is directed to Hardy (1949).

The upper limit of the Twist Gulch Formation has been found clearly exposed in only one place— Salina Canyon, where it is overlain by sandstone, conglomerate, and variegated shale of the Morrison (?) Formation (Spieker, 1946).

The thickness of the Arapien Shale and the Twist Gulch Formation has not been completely resolved. Spieker (1946) estimated the thickness of both at more than 10,000 feet, with the Twist Gulch Formation comprising 3,000 feet and the Arapien Shale about 7,000. Eardley (1933) estimated the thickness of the Jurassic shales (both Arapien Shale and Twist Gulch Formation) at 3,000 to 11,000 feet; and Hunt (1949) estimated that the Arapien Shale is 2,700 feet thick. Hardy (1949) concluded that the Arapien Shale cannot be less than 3,000 feet thick. The great variation in suggested thicknesses undoubtedly are due to the complex structure

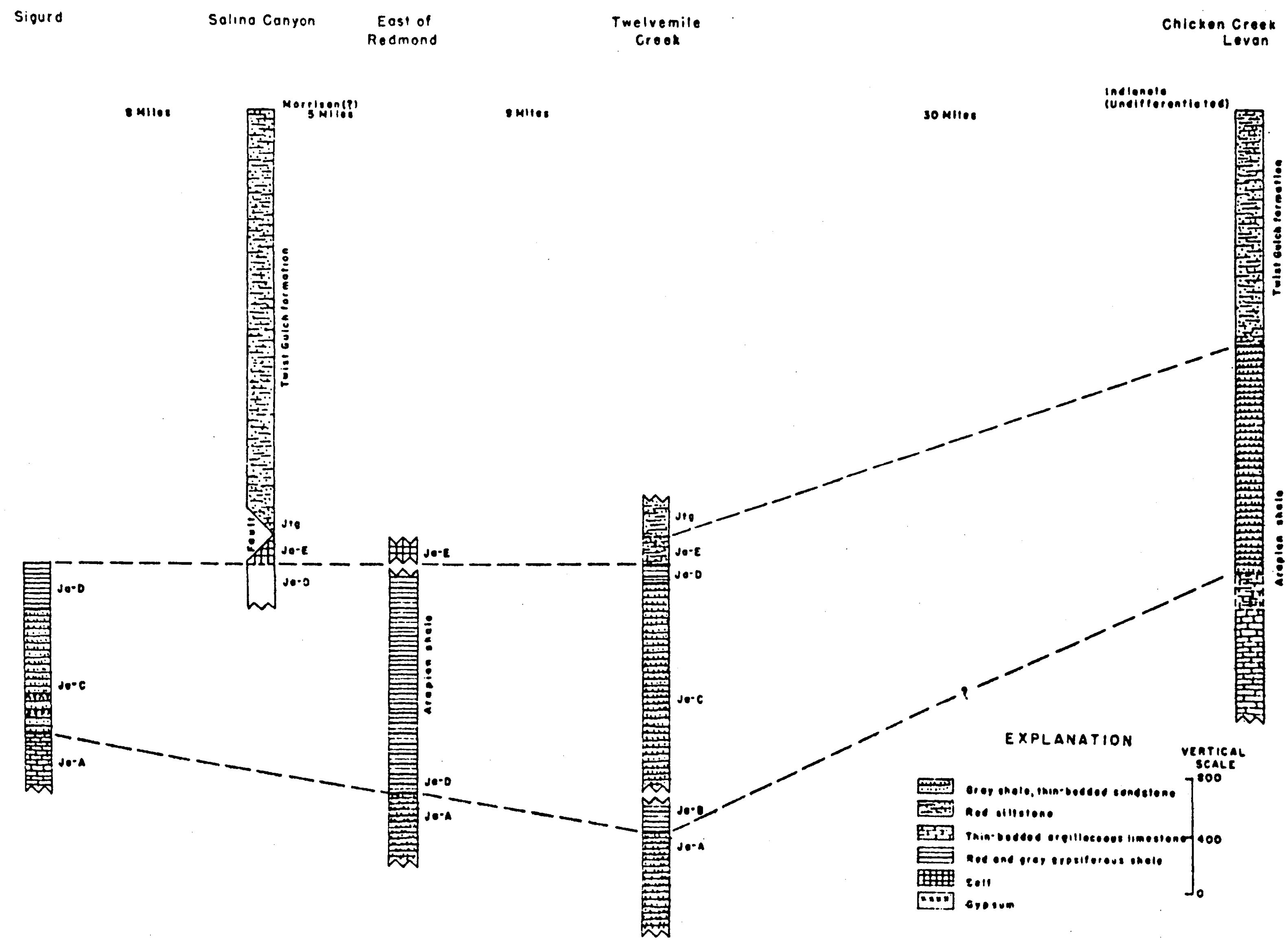


Figure 5. (From Hardy, 1949)

(Gilliand, 1963) and intricate contortions of strata (Spieker, 1946).

The distribution of the Arapien Shale and the Twist Gulch Formation is shown in figures 1 and 6. The largest continuous exposure of Arapien Shale is a belt of low-barren hills two to three miles wide along the eastern margin of the Sevier Valley from Gunnison to Richfield as seen in figure 1 (Hardy, 1949). The shale is also exposed along the western and northern margin of the Gunnison Plateau, where it forms the hills of the Hurricane Cliffs (Hunt,1950). In the Sanpete Valley it is covered by younger units and by alluvium, except in the extreme south where it forms prominent hogbacks.

The Twist Gulch Formation outcrops in Salina Canyon and also in limited exposures southeast of the town of Salina (Figures 1, 6, and 7). Red siltstones characteristic of the Twist Gulch Formation also are found at numerous points along the east front of the Gunnison Plateau (Hardy, 1952). The Twist Gulch Formation also is found beneath thick Indianola conglomerates in the northern part of the Gunnison Plateau as seen in figure 1 (Hardy, 1949).

The relationships of Jurassic strata in Central Utah with Jurassic rocks in the San Rafael Swell, the Southern and Central Wasatch Mountains, Southeast Idaho, and

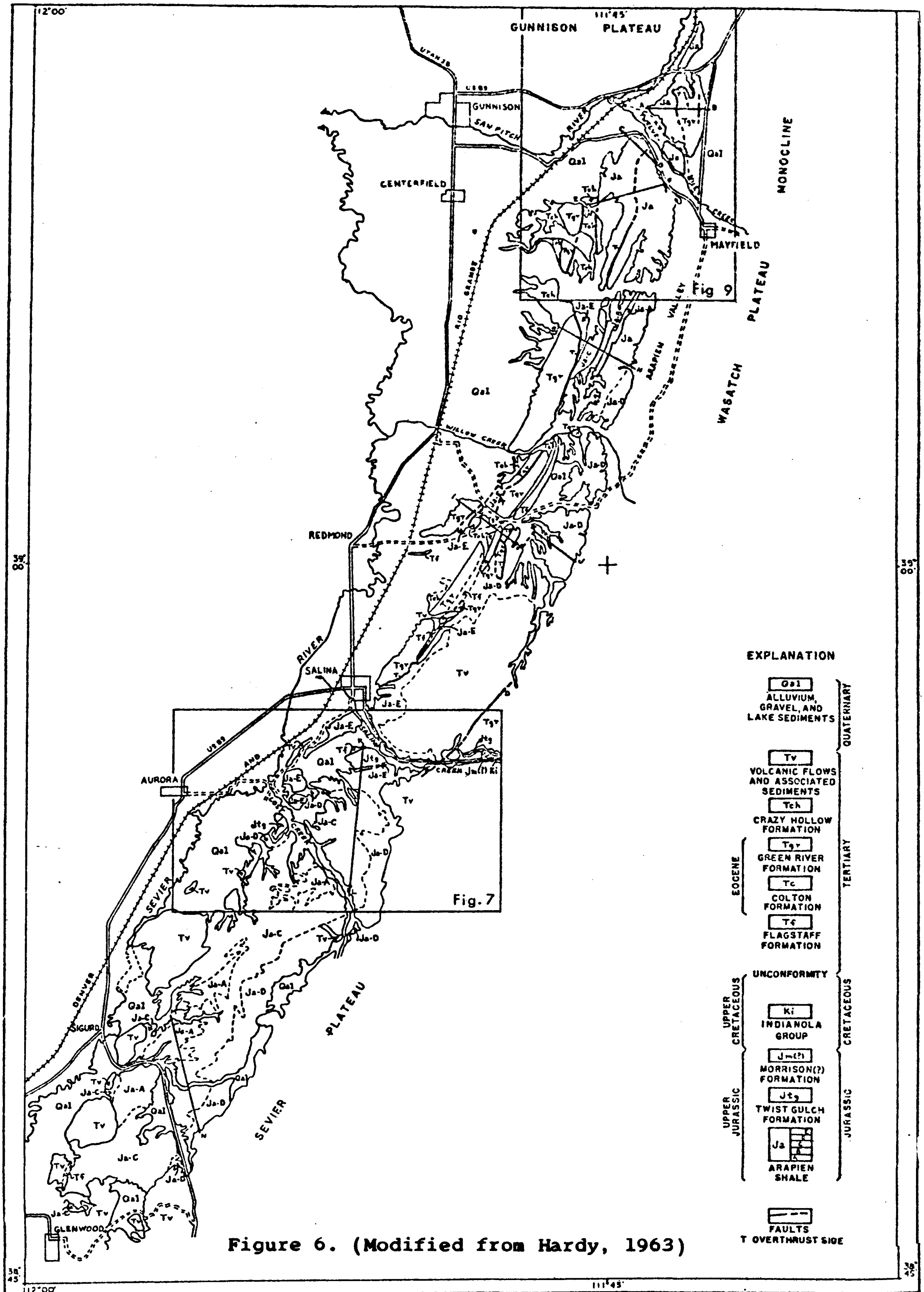


Figure 6. (Modified from Hardy, 1963)

BASE FROM S.C.S. SEMI CONTROLLED MOSAIC.
GEOLOGY MAPPED IN 1947, 1948, AND 1949.

1 0 1 2 3 4 MILES

GEOLOGY BY C.T. HARDY. MARGINAL AREAS IN PART AFTER WM. N. GILLILAND AND E. M. SPIEKER.

Southwestern Utah are given in Table 2. The relationships are based on similar lithology, presumed similar lithologic sequences, and faunal content (Hardy, 1949). However according to Spieker (1946), these relationships are only generalized correlations, and the agreement is not sufficient to warrant the use of formational names from surrounding areas for the rocks in the Sanpete Valley.

Age	San Rafael Swell	Central Utah	Southwest Utah	Central Wasatch Mountains	Southern Wasatch Mountains	Southeastern Idaho
Cretaceous	Morrison	Morrison (?)	Absent	Morrison	Morrison	? Ephraim Conglomerate
Upper Jur. San Rafael gp.	Summerville	Twist Gulch		Twin Creek Limestone		
	Curtis / Moab Ss. mbr.		Curtis		? Curtis	? Stump
	Entrada		Entrada		Entrada	Absent / Preuss
	Carmel	Arapien Shale	Carmel		Twin Creek Limestone	?
Jurassic Glen Canyon gp.	Navajo Sandstone	Navajo Sandstone	Navajo Sandstone	Nugget Sandstone	Nugget Sandstone	? Absent
	Kayenta	?				Nugget Sandstone
Triassic	Wingate Sandstone		Absent	Absent		
	Chinle		Chinle	Ankareh		

Table 2. Stratigraphic Nomenclature in Utah and Idaho (Modified from Hardy, 1949).

FIELD STUDIES

Field studies were conducted during the summer of 1978. Samples numbered 3001 to 3044 were collected from two areas: 1) Salina Canyon, and 2) the hogback adjacent to Ninemile Reservoir (Figure 25 and 26).

Samples for chemical analysis were collected at approximately every 200 to 300 feet of stratigraphic thickness or as warranted by significant lithologic changes. Most of the samples consisted of several small chips (up to 2 cm in diameter) collected in a radius of approximately 2 meters. This method of collection was employed to give an unbiased sample for each collection site.

Representative hand specimens were collected where pertinent litholgic or mineralogic relationships existed. Samples 3043 and3044 were collected from vein deposits within an abandoned mine east of the Lead Hill Mine. All sample locations are given in figures 25 and 26 in Appendix B.

GEOLOGY OF THE SALINA CANYON AREA

The geology of the Salina Canyon area is shown in figures 7 and 8. An anticline trends northeast obliquely across Salina Creek in the lower part of Salina Canyon. On the east limb of the anticline the Arapien Shale is nearly vertical adjacent to a north-south-trending normal fault (Figure 8). East of the fault, the Twist Gulch Formation is nearly vertical and is overlain in angular unconformity by Flagstaff Limestone, and Colton and Green River formations (Hardy, 1949). The nearly vertical dip flattens eastward and at Rattlesnake Hill about a mile east of the Twist Gulch-Morrison (?) formational contact it is 30 to 40 degrees east (Loughlin, 1920). The Flagstaff Limestone thickens to the east from a feather edge directly above the Twist Gulch Formation suggesting that the anticline was exposed continuously during the time of Flagstaff deposition (Hardy, 1949). The presence of an horizon of red-colored paleosol between the Twist Gulch Formation and the Flagstaff Limestone (Loughlin, 1920) levels support to this conclusion.

Several stages of normal faulting are present in the area (Spieker, 1930). Some faulting precedes tilting of the Wasatch Monocline, some is contemporaneous with tilting, and some is later. The extent to which this movement affected the Arapien Shale and the Twist Gulch Formation cannot

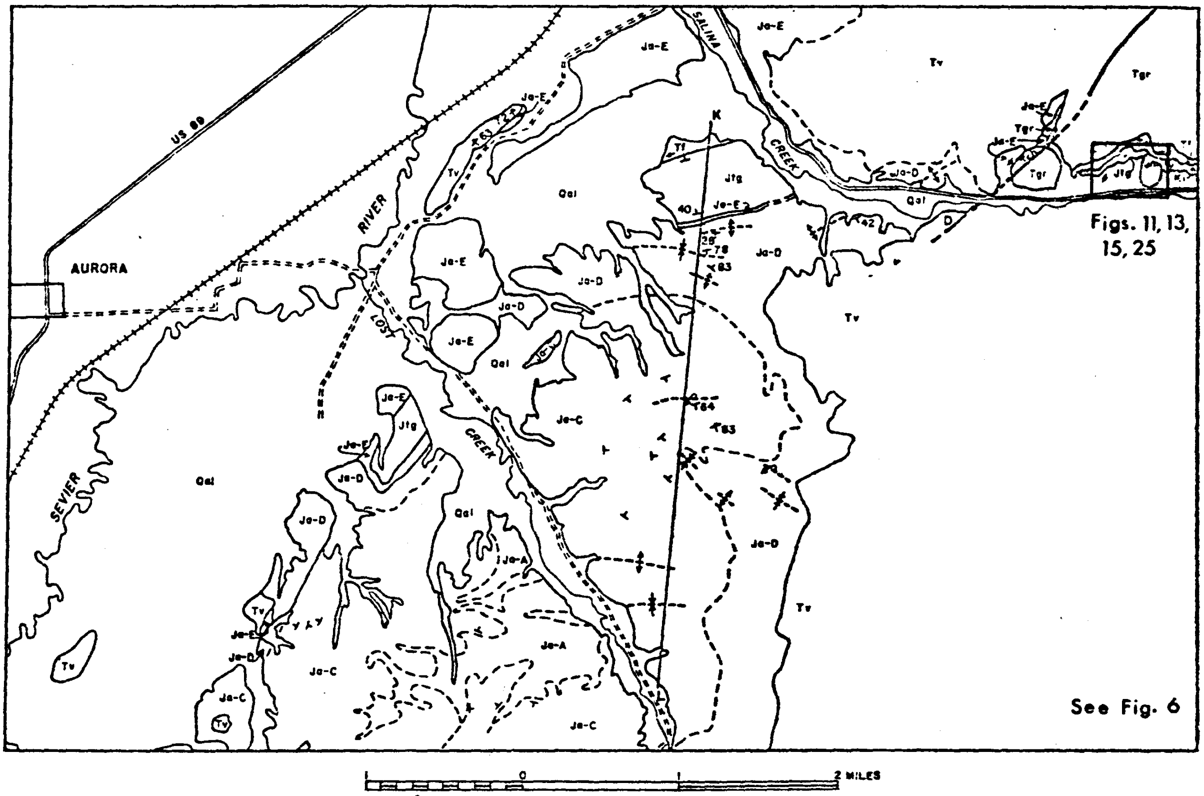
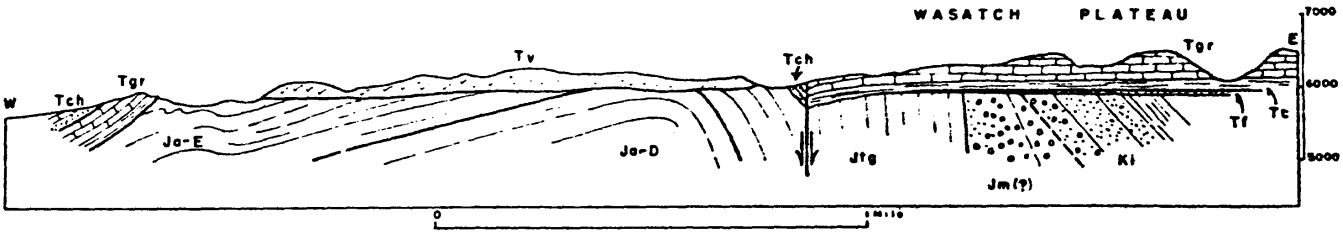


Figure 7. Detailed Map of Area South of Salina, Utah (Modified from Hardy, 1952)



B. Salina Canyon.

Tnh -North Horn formation
Kpr -Price River formation
Ki -Indianola group
Jm(?)-Morrison(?) formation
Jtg -Twist Gulch formation
Ja -Arapien shale
Tv-Volcanic flows
Tch-Crazy Hollow formation
Tgr-Green River formation
Tc -Colton formation
Tf -Flagstaff formation

Figure 8. Salina Canyon (From Hardy, 1949)

presently be determined (Hardy, 1949). Samples 3001 through 3025 were collected along the north side of Salina Canyon in the S. ½, Sec. 33, T. 21 S., R.1 E. (Figure 25). This site is the type locality of the Twist Gulch Formation and about 1900 feet of the rock is exposed. This site was chosen also to determine the relationships between the trace metal chemistry of the rocks in outcrop and the chemistry of rocks within several small mines located near the fault (Figure 25).

GEOLOGY OF THE NINEMILE RESERVOIR AREA

The geology of the Ninemile Reservoir area is shown in figure 9. Samples 3026 through 3042 were collected on a hogback located in the W. $\frac{1}{2}$, Sec. 8, T. 19 S., R. 2 E. (Figure 26). The hogback lies along the west limb of the Sevier-Sanpete Valley anticline. At this locality units B and C of the Arapien Shale strike northeast and are overturned, dipping 66 to 68 degrees east (Figures 3and 4). The strata are conformable with the Morrison (?) Formation exposed to the west along the east margin of the Gunnison Plateau.

The area was chosen because it is relatively undeformed and is easily accessible.

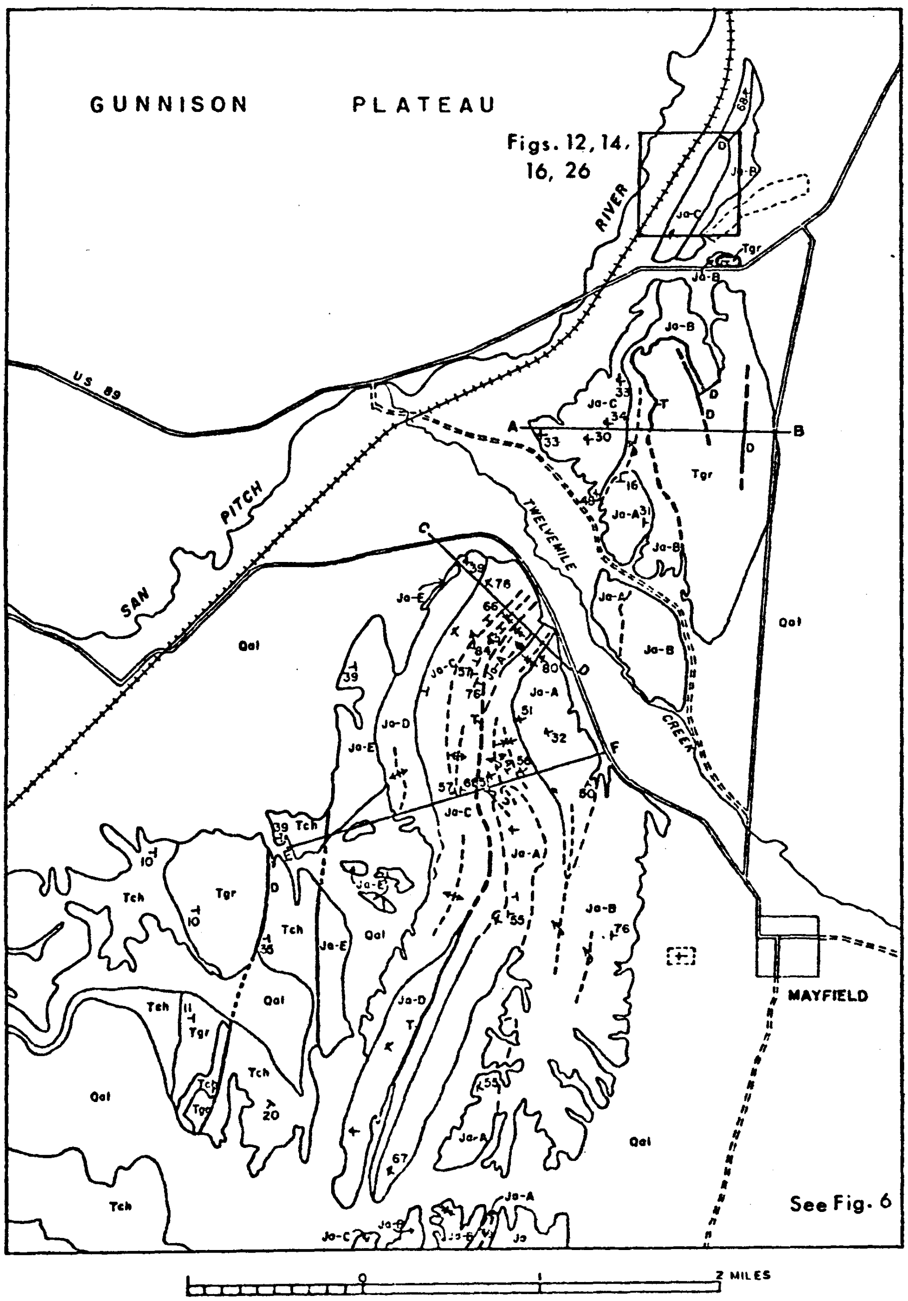


Figure 9. Detailed Geologic Map of Area East of Gunnison, Utah. (Modified from Hardy, 1952)

TRACE METAL GEOCHEMISTRY OF THE ARAPIEN SHALE AND THE TWIST GULCH FORMATION

All samples were analyzed for copper, lead, zinc, and silver by atomic absorption spectrophotometry. See Appendix A for sample preparation and analytical procedures.

Analytical Results

The concentrations of copper, lead, and zinc are summarized in figure 10, and in table 3. They also are plotted in figures 11 through 16. Individual sample results are tabulated in Appendix B. Analyses were conducted for silver, but all values fell below the lower detection limit for the atomic absorption unit. Samples 3043 and 3044 were taken from vein deposits within the mines located on figures 11, 13, 15, and 25. The results of these analyses are plotted on figure 18 and table 4, but were not used in the calculations of mean, median, mode, and ranges in concentration. They represent epigenetic mineralization and thus do not represent the trace metal chemistry of the Arapien Shale or the Twist Gulch Formation. Comparisons of the trace metal chemistry with that of other shales and with crustal abundances are shown in figure 17. Copper generally is depleted in both Arapien Shale and Twist Gulch Formation when compared with other shales and with average crustal abundances; zinc is slightly higher than average; and lead is subtly enriched.

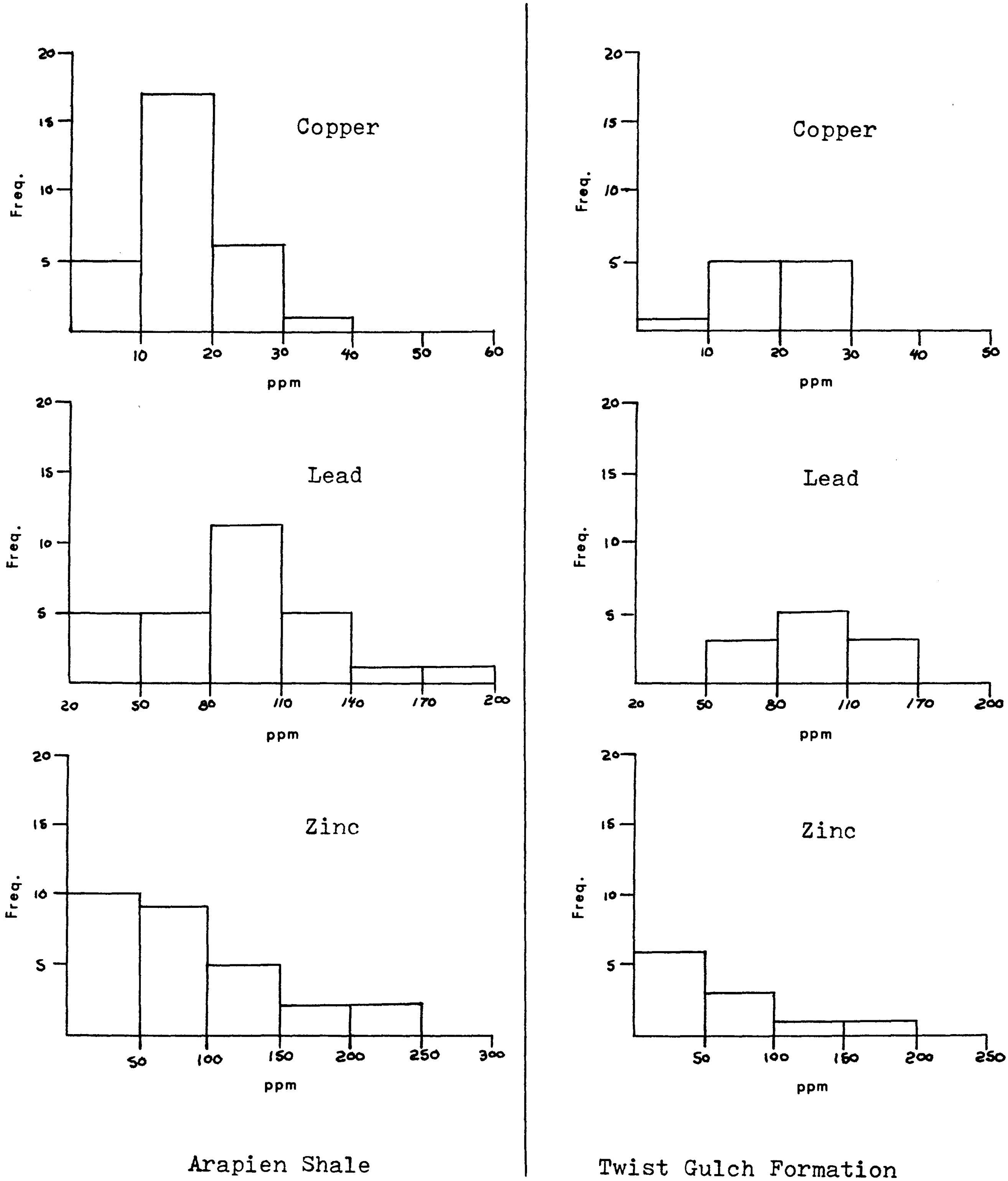
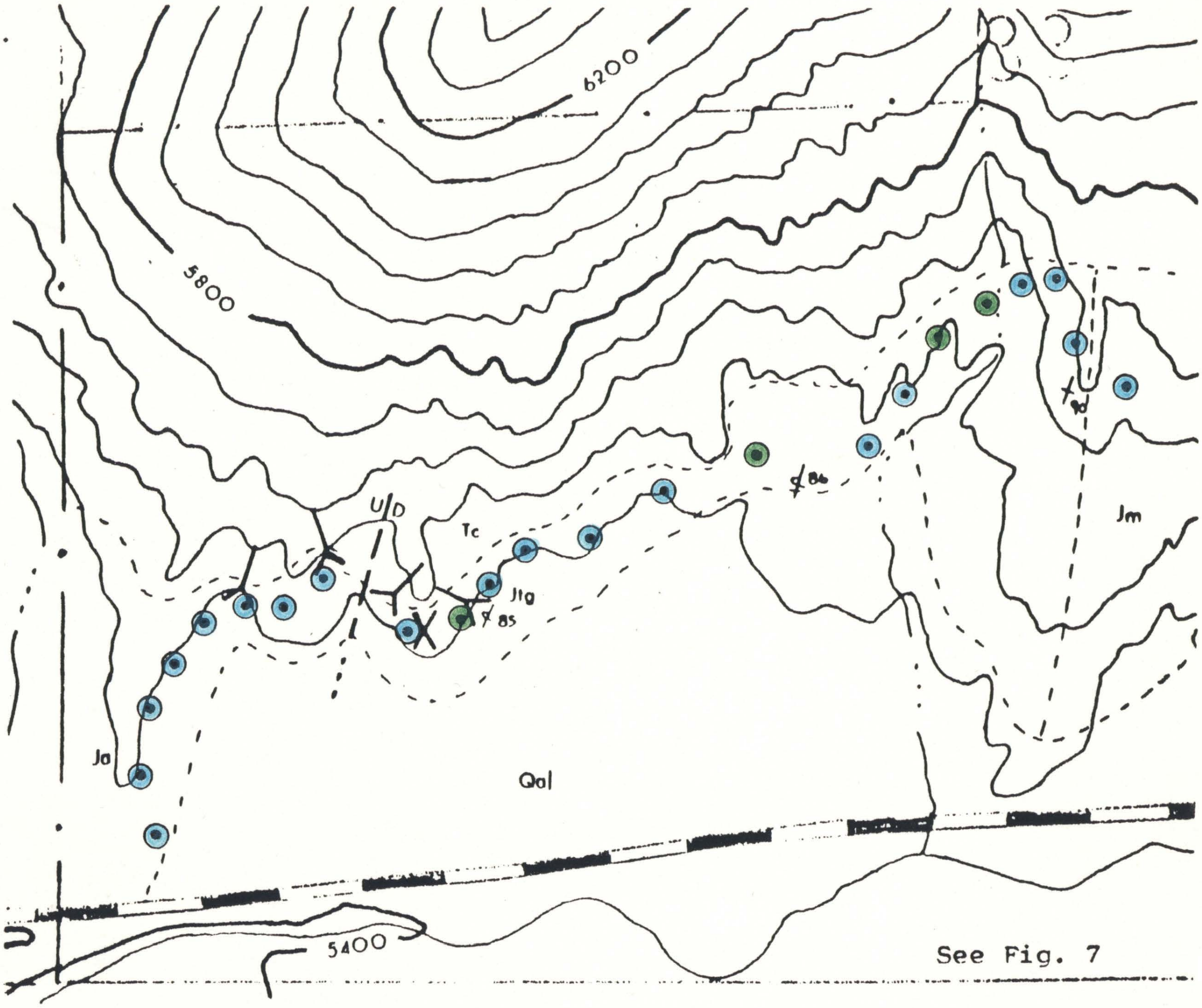

Copper
Lead
Zinc
Freq.
ppm
Arapien Shale
Twist Gulch Formation

Figure 10.

Table 3.

	Arapien Shale			Twist Gulch Formation		
	Cu	Pb	Zn	Cu	Pb	Zn
Mean	15	91	140 ppm	17	98	111 ppm
Median	16	90	118 ppm	12	90	86 ppm
Mode	16	—	118 ppm	11	—	— ppm
Range	6 - 36	28 - 169	53 - 407 ppm	6 - 27	60 - 144	71 - 210 ppm



CONTOUR INTERVAL 80 FEET
DATUM IS MEAN SEA LEVEL

0 1000 feet
SCALE

Explanation

Copper ppm

- <25
- 25-36
- 37-48
- > 48

N

Figure 11.

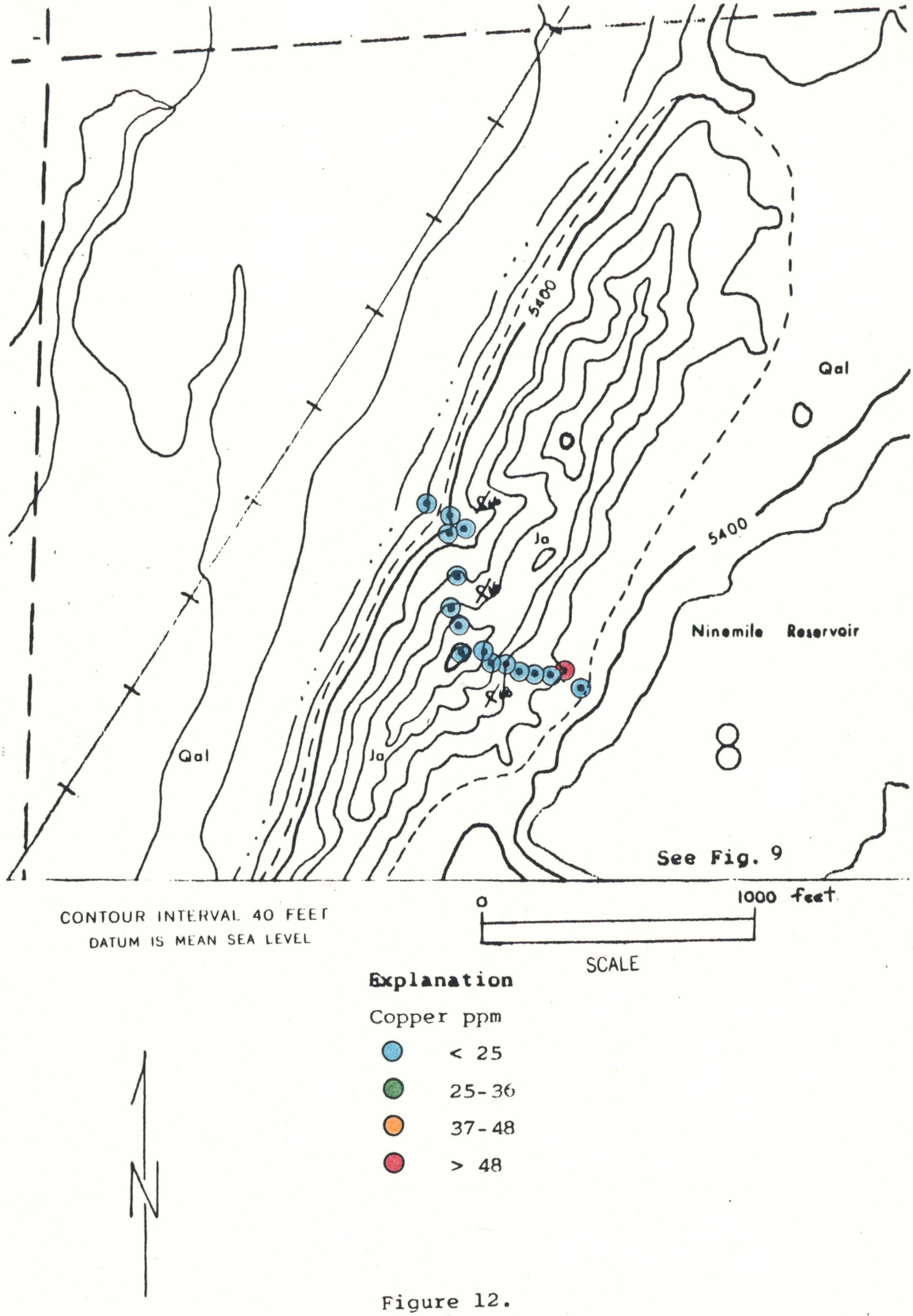

5400
5400
Qal
Qal
Qal
Ja
Ja
Ninemile Reservoir
8
See Fig. 9
0
1000 feet
SCALE
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
Explanation
Copper ppm
< 25
25-36
37-48
> 48
N

Figure 12.

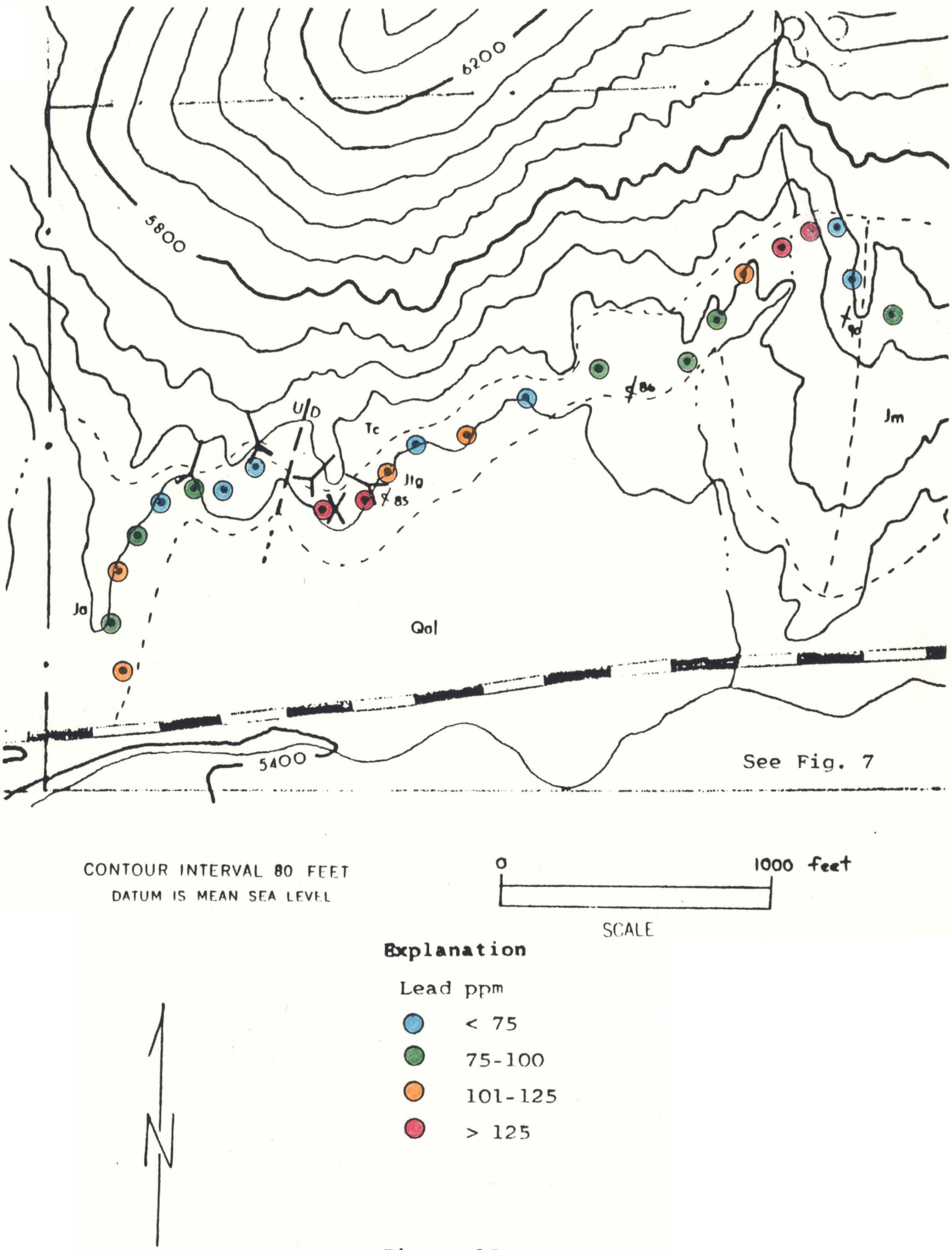
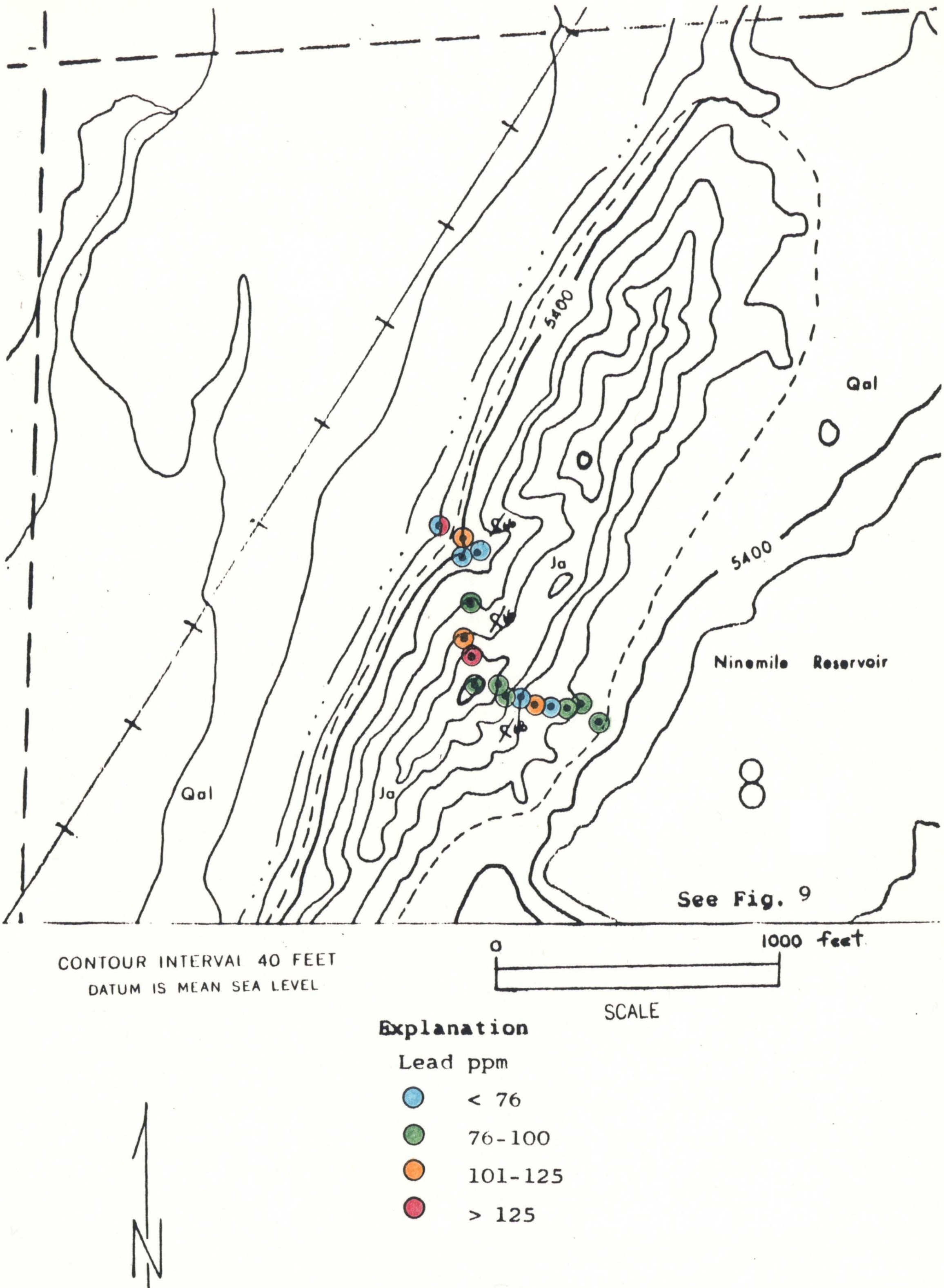
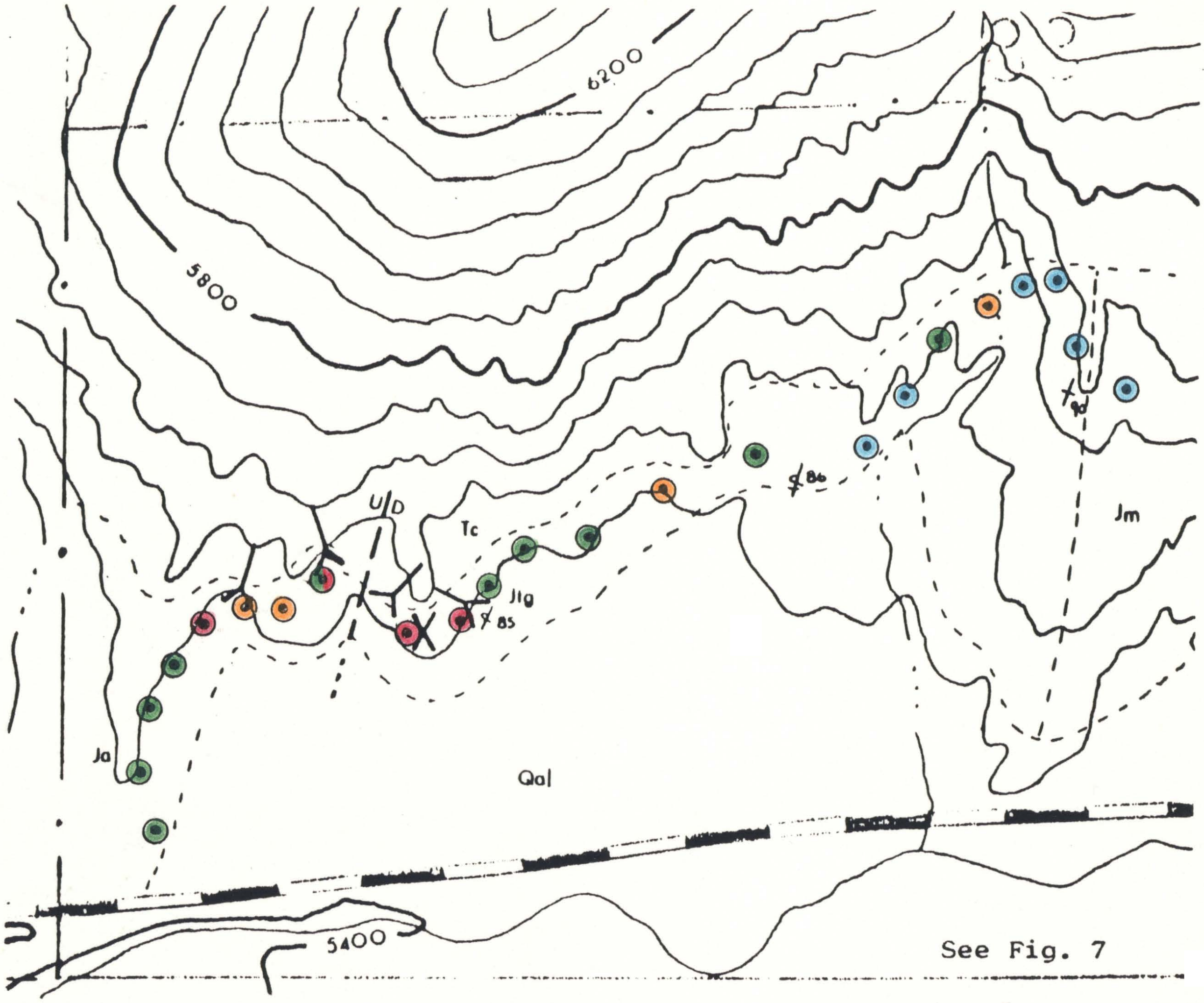

6200
5800
5400
U/D
Tc
Jlg
85
84
80
Jm
Ja
Qal
See Fig. 7
CONTOUR INTERVAL 80 FEET
DATUM IS MEAN SEA LEVEL
0
1000 feet
SCALE
Explanation
Lead ppm
< 75
75-100
101-125
> 125
N

Figure 13.



5400
Qal
Ja
5400
Ninemile Reservoir
8
Qal
Ja
See Fig. 9
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
0
1000 feet
SCALE
Explanation
Lead ppm
< 76
76-100
101-125
> 125
N

Figure 14.



CONTOUR INTERVAL 80 FEET
DATUM IS MEAN SEA LEVEL

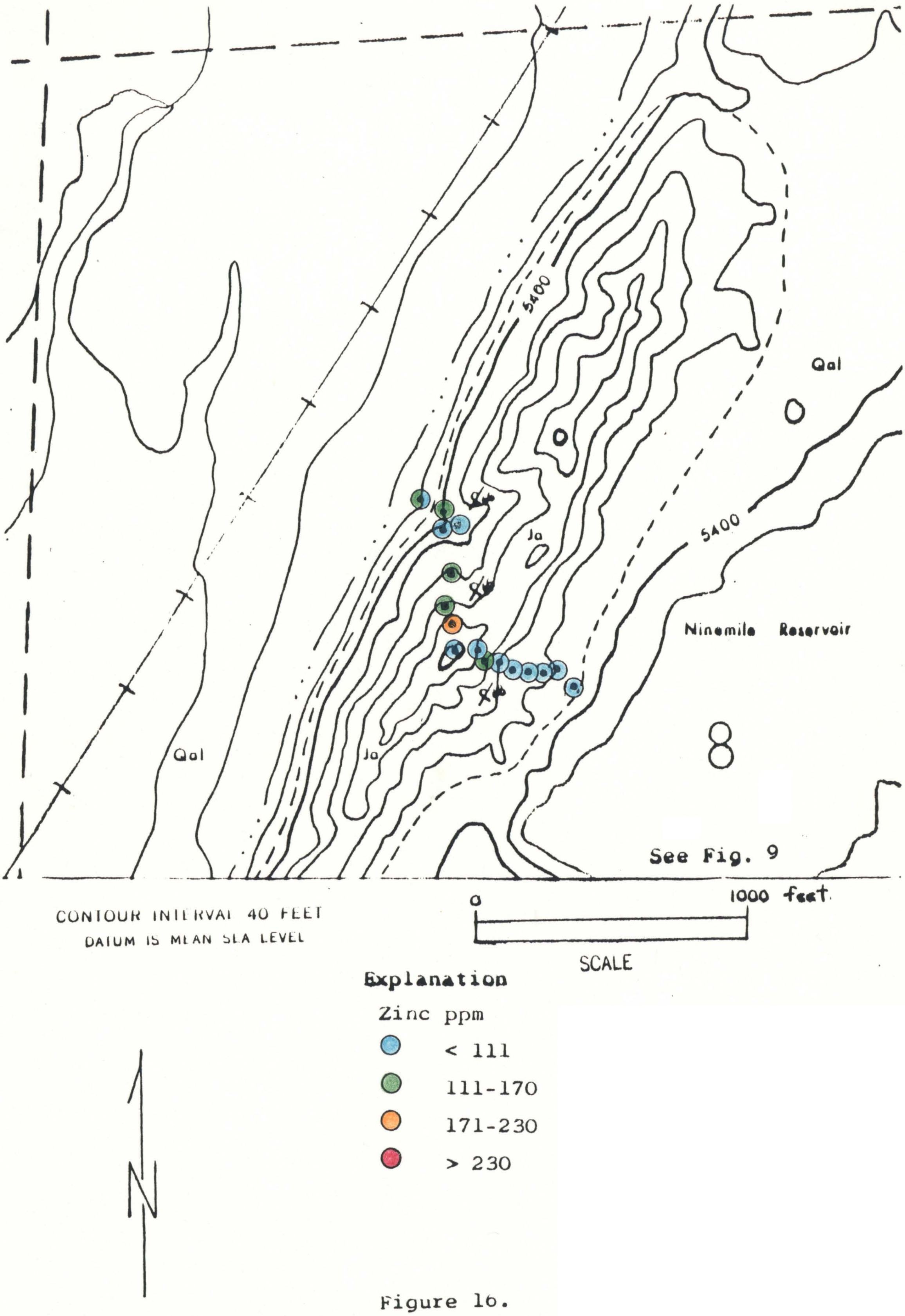
0 1000 feet
SCALE

Explanation

Zinc ppm

- < 111
- 111-170
- 171-230
- > 230

Figure 15.



5400
Qal
Ja
5400
Ninemile Reservoir
8
Qal
Ja
See Fig. 9
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
0
1000 feet
SCALE
Explanation
Zinc ppm
< 111
111-170
171-230
> 230
N

Figure 16.

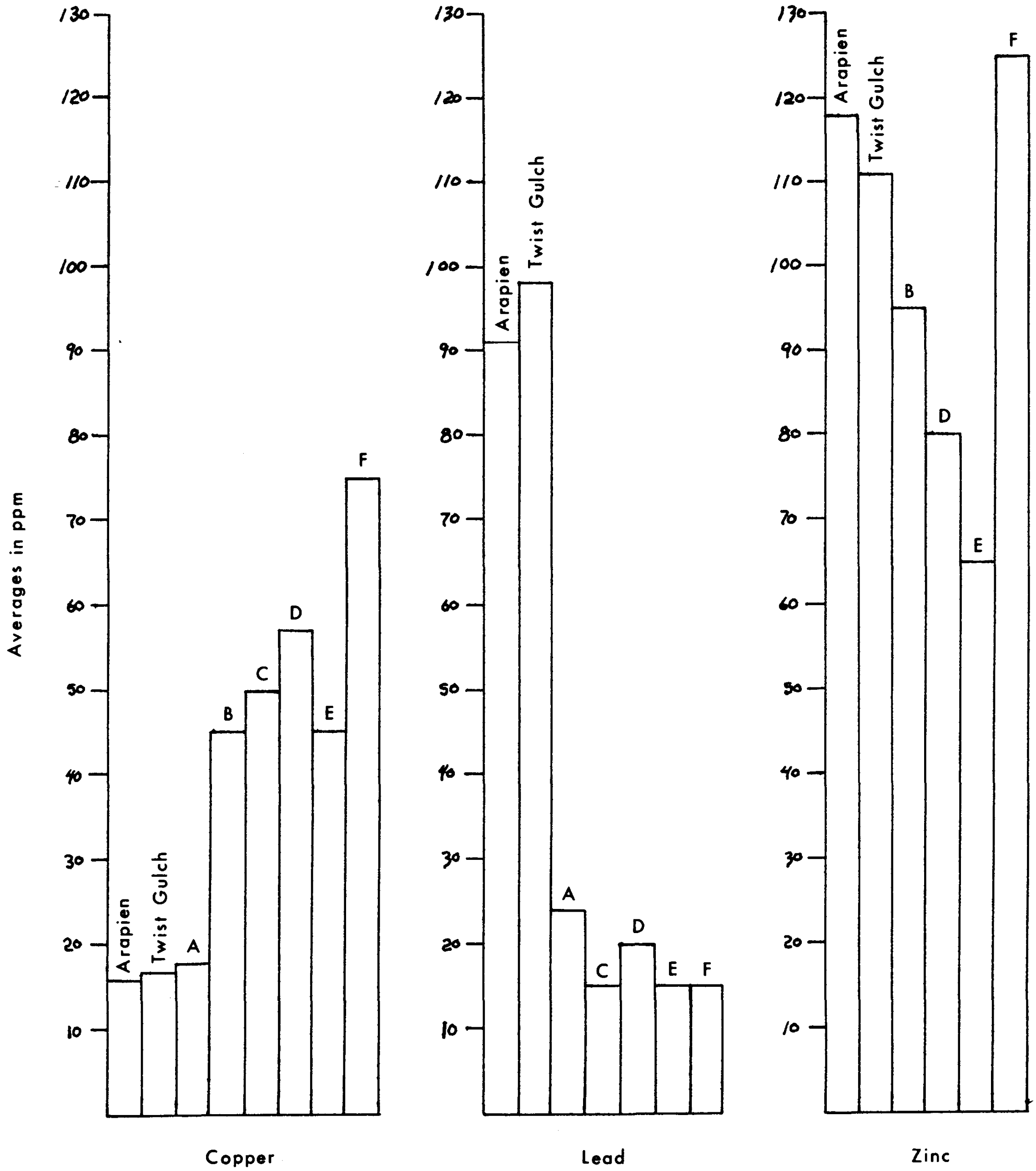


Figure 17. Comparison of Arapien Shale and Twist Gulch Formation average trace metal content with other shales and crustal abundances.

Shales:
- A - Shaw (1954)
- B - Turkein and Wedepohl (1961)
- C - Tourtelot (1962)
- D - Andrews-Jones (1968)

Crustal Abundances:
- E - Mason (1958)
- F - Andrews-Jones (1968)

Interpretation of Results

The Arapien Shale and the Twist Gulch Formation are closely related with respect to their copper, lead, and zinc concentrations. The relationship copper : lead : zinc is shown in figure 18. From this data and from that in figure 17 it is likely that the Arapien Shale and the Twist Gulch Formation were derived from a similar source, the same conclusion made by Baker et al. (1936). The source probably was igneous and located to the northwest. The subtle enrichment in lead and zinc suggests that the source also may have contained anomalous concentrations of these metals. Shaw (1954) pointed out that in general the trace element contents in shales are what one would expect from the erosion and transportation of an average igneous rock, except for copper, which usually shows a loss in concentration in the shale. This could explain the depletion in copper within the Arapien Shale and the Twist Gulch Formation as shown in figure 18.

Sample 3042 is highly enriched in copper (532 ppm), with respect to lead and zinc. This sample was taken from a highly gypsiferous bed within unit C of the Arapien Shale west of Ninemile Reservoir (Figure 12 and 26). It may reflect syngenetic enrichment in copper according to the sabkha process summarized by Renfro (1974).

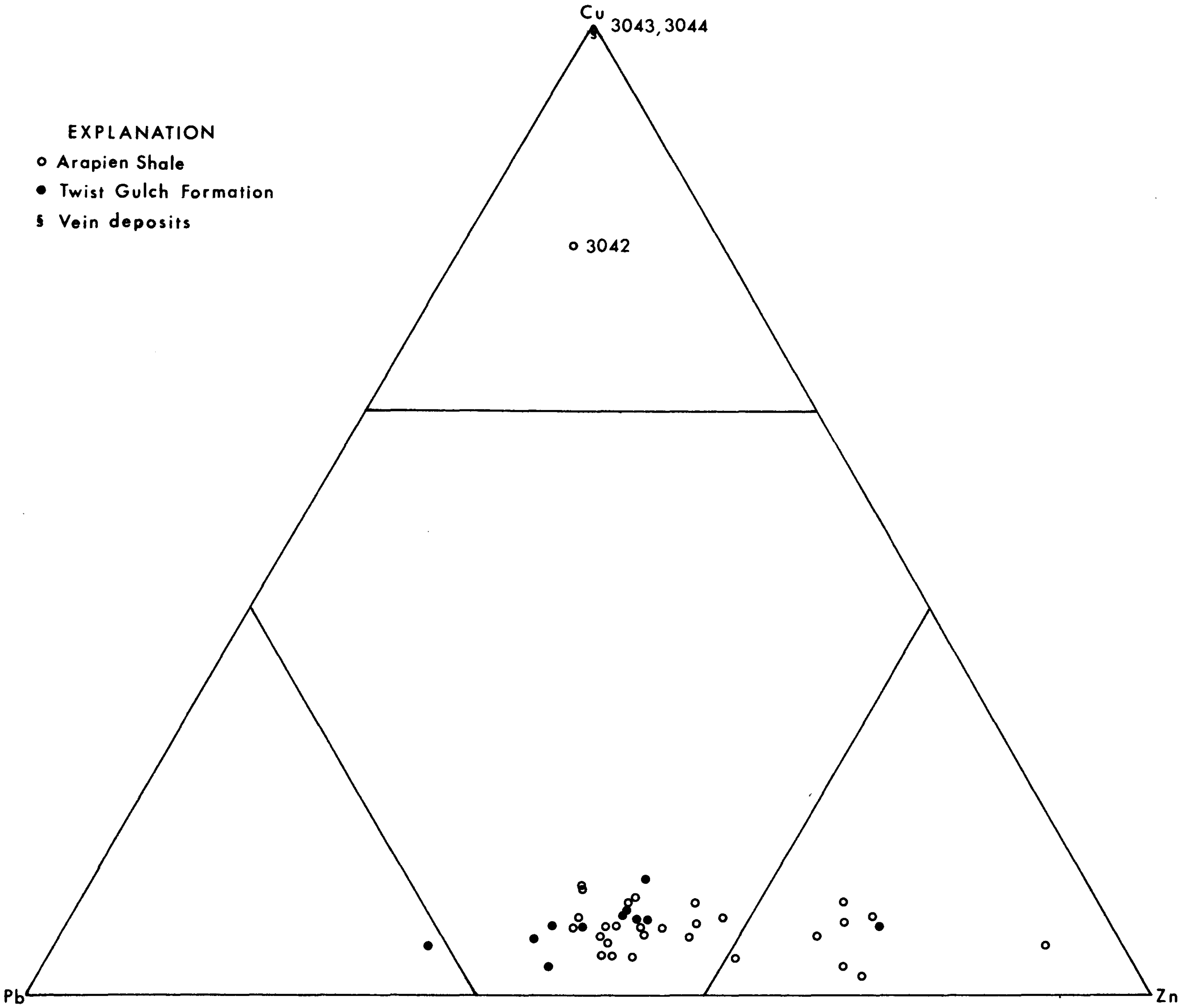

Cu
3043, 3044
EXPLANATION
o Arapien Shale
• Twist Gulch Formation
§ Vein deposits
o 3042
Pb
Zn

Figure 18.

A sabkha is an evaporite flat bordering a partially landlocked regressive sea. these flats are supplied with metal-bearing, high Eh- low pH, terrestrial ground water, which mixes with low Eh- high pH, landward migrating marine waters. Through evaporative pumping these waters subsequently are drawn upward through decaying algal mats. The decaying mats produce hydrogen sulfide, which combines with the mixture of terrestrial and marine waters to precipitate interstitial metal sulfides. These deposits are: 1) laterally and vertically zoned with respect to metal content; 2) overlain by strata containing dolomite, gypsum, anhydrite, and halite; and 3) underlain by red beds or otherwise oxidized continental clastic sediment (Renfro, 1974). These relationships are shown in figure 19, and the general process is summarized in figure 20.

The Arapien Shale in places may represent a Jurassic sabkha. It is intimately associated with evaporite beds, fossiliferous arenaceous limestones, and oxidized red beds. It is also underlain by aeolian sands of the Navajo Sandstone. These relationships may represent a sabkha-type model of mineralization, however, more is needed on the evaporite-bearing portions of the Arapien Shale to draw any further conclusions.

Mineralization in the Salina Canyon area was first

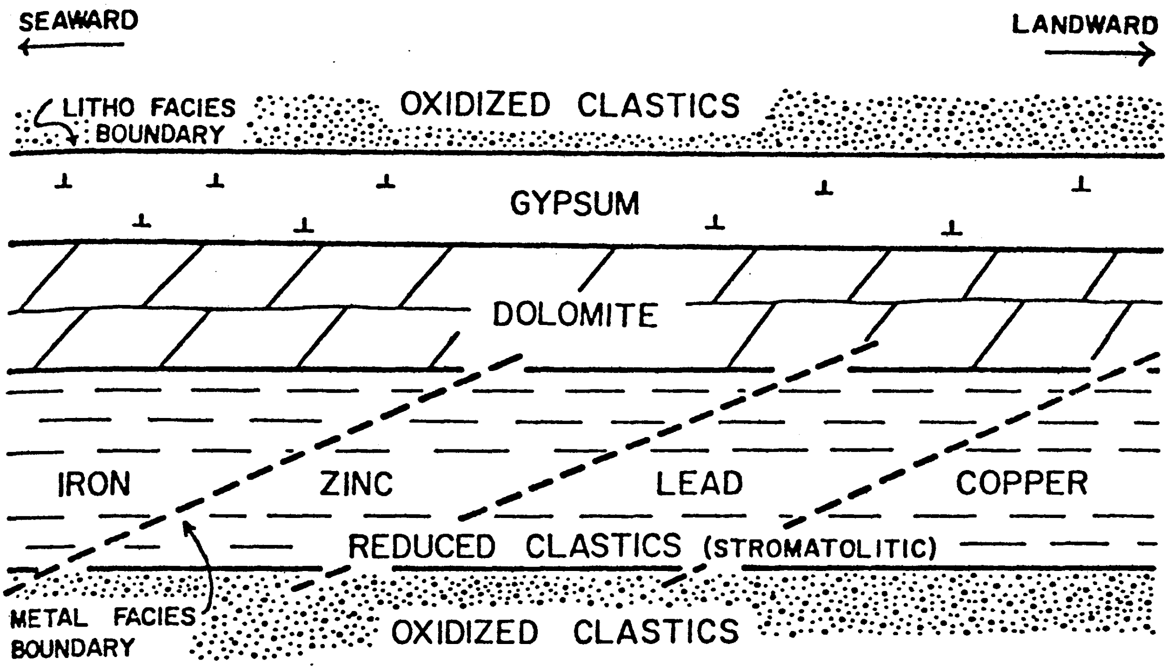


Figure 19. (From Renfro, 1974)

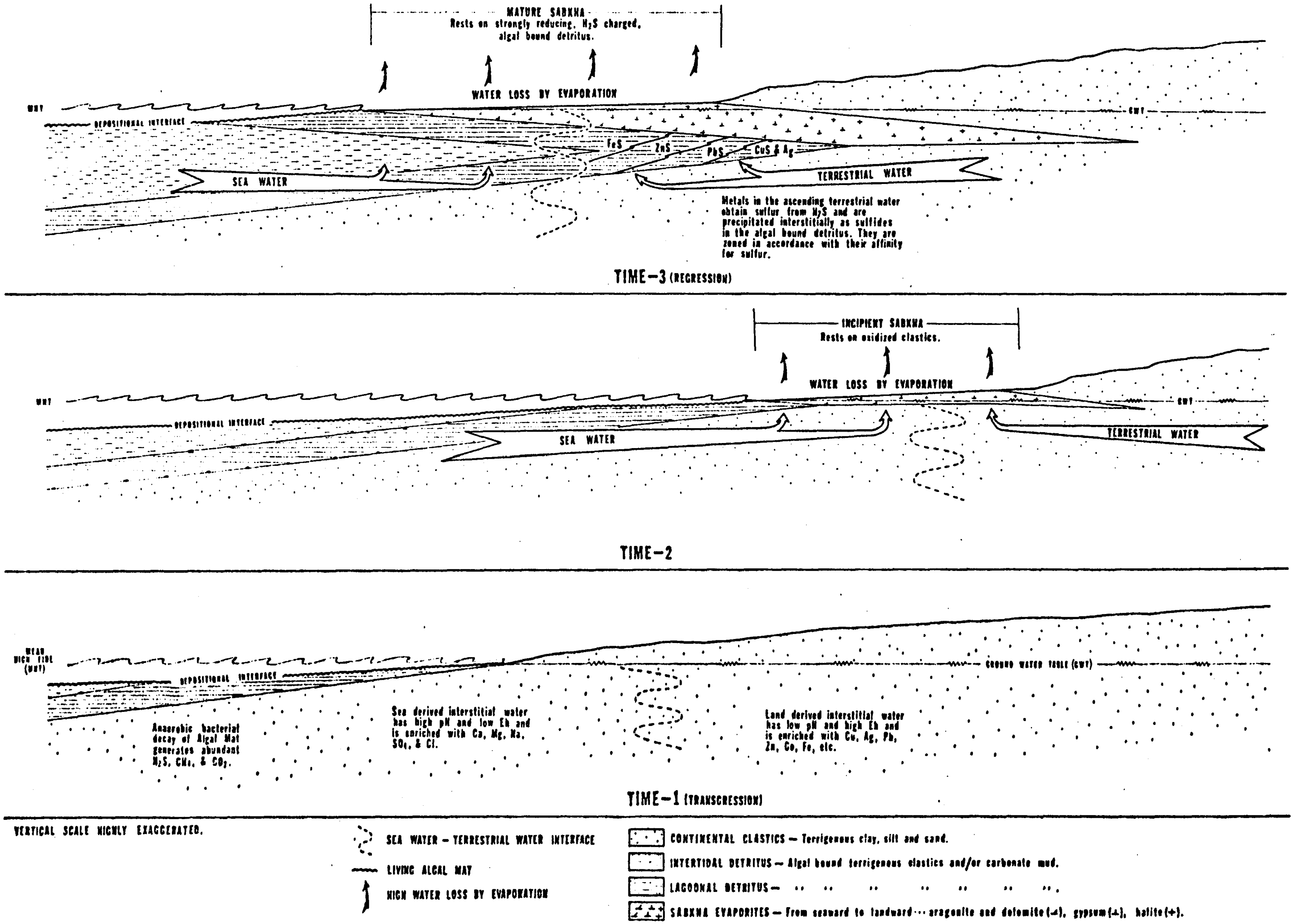


Figure 20. (From Renfro, 1974)

reported by G. F. Loughlin (1920). The main occurance in the canyon was at the Lead Hill Mine located about four miles east of the town of Salina. The Lead Hill Mine produced lead and zinc concentrates from 1908 to 1912. The workings of the mine followed a Jurassic age drainage network that now is filled with red and white sandstones of the Colton Formation. The ore and gangue minerals were galena, cerrusite, sphalerite, pyrite, chalcocite, malachite, azurite, and celestite (Loughlin, 1920).

Additional mines were situated east of the Lead Hill Mine and are shown in figures 11, 13, 15, and 25. Examination of mine dumps and covered workings indicate that the ore consisted of veinlets and disseminations of chalcocite, azurite, and malachite. The anomalous zinc content in sample 3002 (wall rock from the mine), and the slightly anomalous lead content in the rocks surrounding the mines (Figure 13 and 15) suggest that some zinc and lead mineralization also may have been present.

The origin of the mineralization is not clear. It may have been associated with ascending mineralized solutions from an igneous source. The normal faults throughout the area could have provided avenues of ascent for these solutions, which then traveled along the angular unconformity into the more permeable sandstones of the Colton Formation. The general lack of wall rock alteration suggests that the fluids may have been telethermal and that the metals were carried as complex ions. The ions in the hydrothermal fluids may have reacted with the calcareous cement of the sandstone to produce the metal carbonates, azurite and malachite.

Some evidence suggests that the mineralization in Salina Canyon was perhaps the result of supergene phenomena, the metals coming from weathering lava flows in the area. The proximity of the anomalous trace metal values to the normal faulting indicates that the two somehow are related. The mineralization may have been much later than the faulting.

CONCLUSIONS

There is evidence of syngenetic as well as epigenetic enrichment in both the Arapien Shale and the Twist Gulch Formation, and while the enrichment is not of economic proportions, the possibility exists of significant base- and precious-metal concentrations. The most favorable areas of future investigation are those sites of significant evaporite and related sediment deposition (the so-called sabkha-type enviroment). Sites of possible significant epigenetic mineralization include the fault zones that flank the Sevier and Sanpete Valleys.

AKNOWLEDGEMENTS

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APPENDIX A: ATOMIC ABSORPTION ANALYSIS

General Procedure

Lead, zinc, copper, and silver concentrations were determined using a Perkin-Elmer 303 atomic absorption spectrophotometer equipped with a Perkin-Elmer 165 strip-chart recorder and appropriate hollow cathode tubes.

Instrument settings, gas flow rates, and preparation of standard solutions were obtained from the Perkin-Elmer Methods Handbook (1971 ed.). Standard working curves are shown in figures 21 through 24. The curves and their respective equations were generated by a least squares linear regression. The correlation coefficients, r, are shown for each standard working curve and were calculated using the equation:

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{n\Sigma(x^2) - (\Sigma x)^2}\,\sqrt{n\Sigma(y^2) - (\Sigma y)^2}}, \text{ where}$$

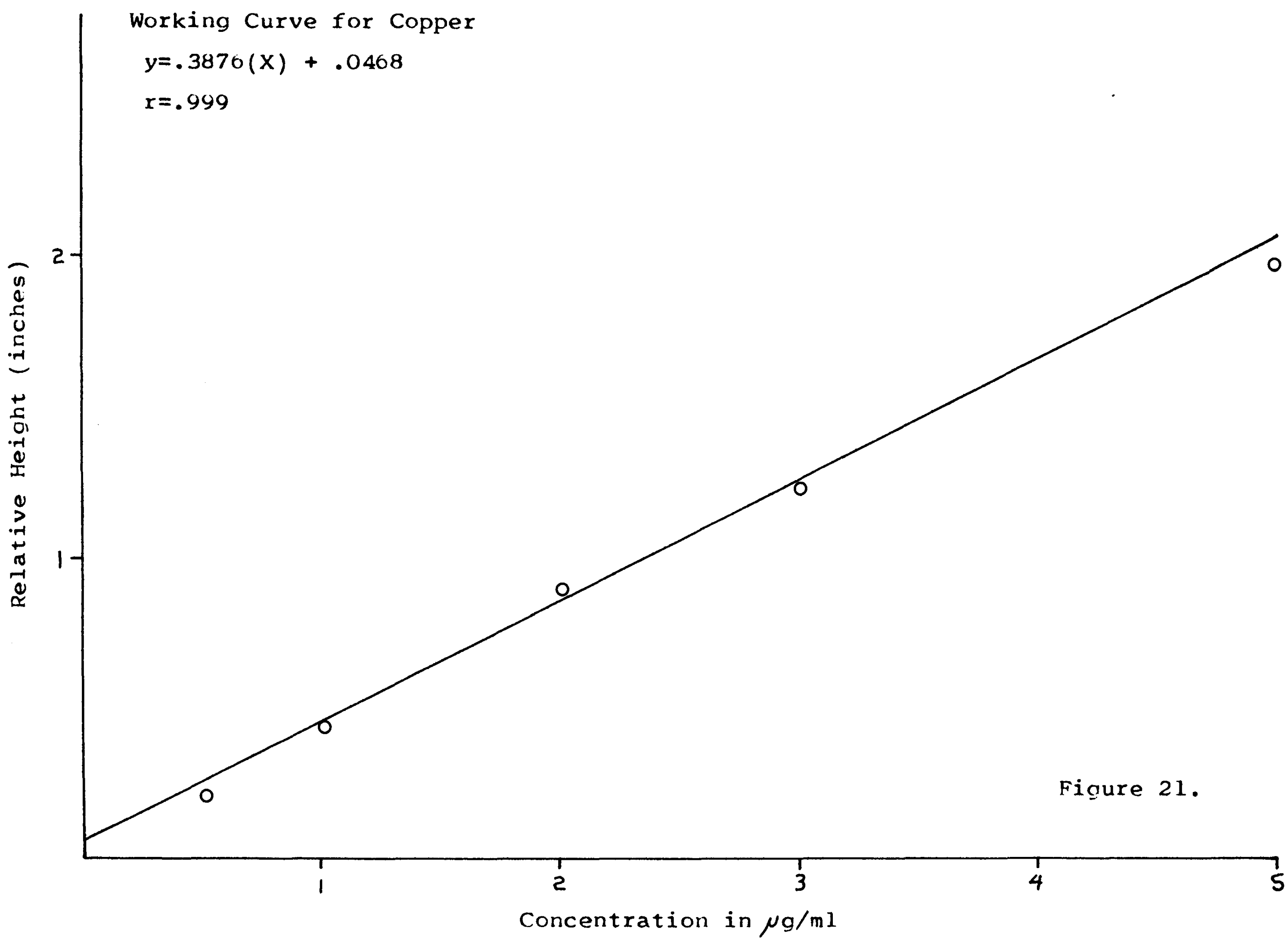
n is equal to the number of standard concentrations used, y is the relative peak height in inches, and x is the concentration in ppm of the respective standard solutions.

The correlation coefficient ranges from -1 to +1 and reflects the "fit" of a straight line to the data points (negative or positive slope respectively). Zero indicates no fit.

The concentration of metal in a sample was calculated from the equation:

$$ppm = \frac{(C)(V)(d.\ f.)}{W}, \text{ where}$$

C is the concentration of a metal in μg/ml in the sample solution (obtained from the working curve), V is the volume of sample solution, d. f. the dilution factor (if used), and W is the weight of rock powder in grams.



Working Curve for Copper
y=.3876(X) + .0468
r=.999
Relative Height (inches)
2
1
1
2
3
4
5
Concentration in µg/ml

Figure 21.

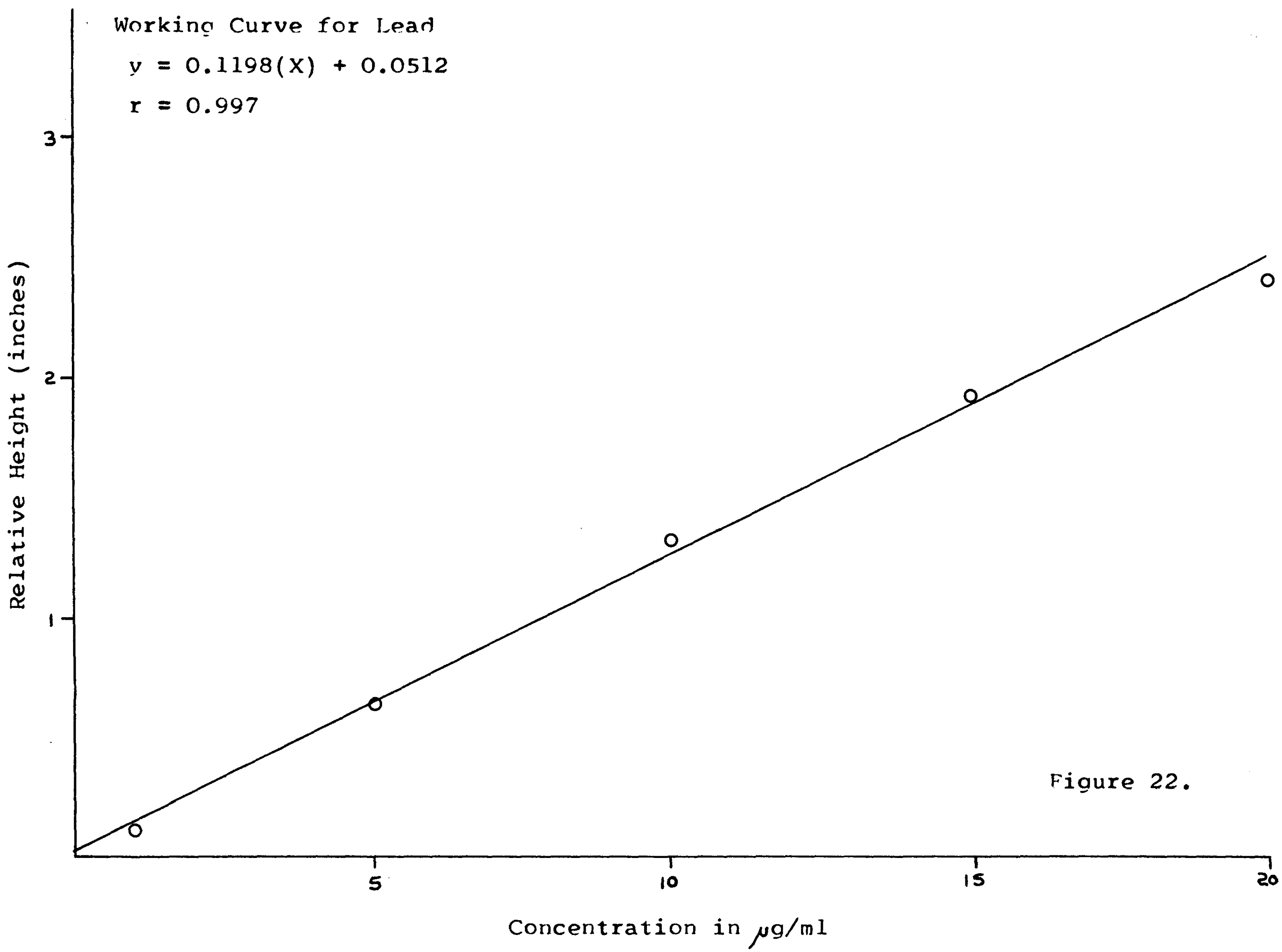

Working Curve for Lead
y = 0.1198(X) + 0.0512
r = 0.997
Relative Height (inches)
1
2
3
5
10
15
20
Concentration in μg/ml

Figure 22.

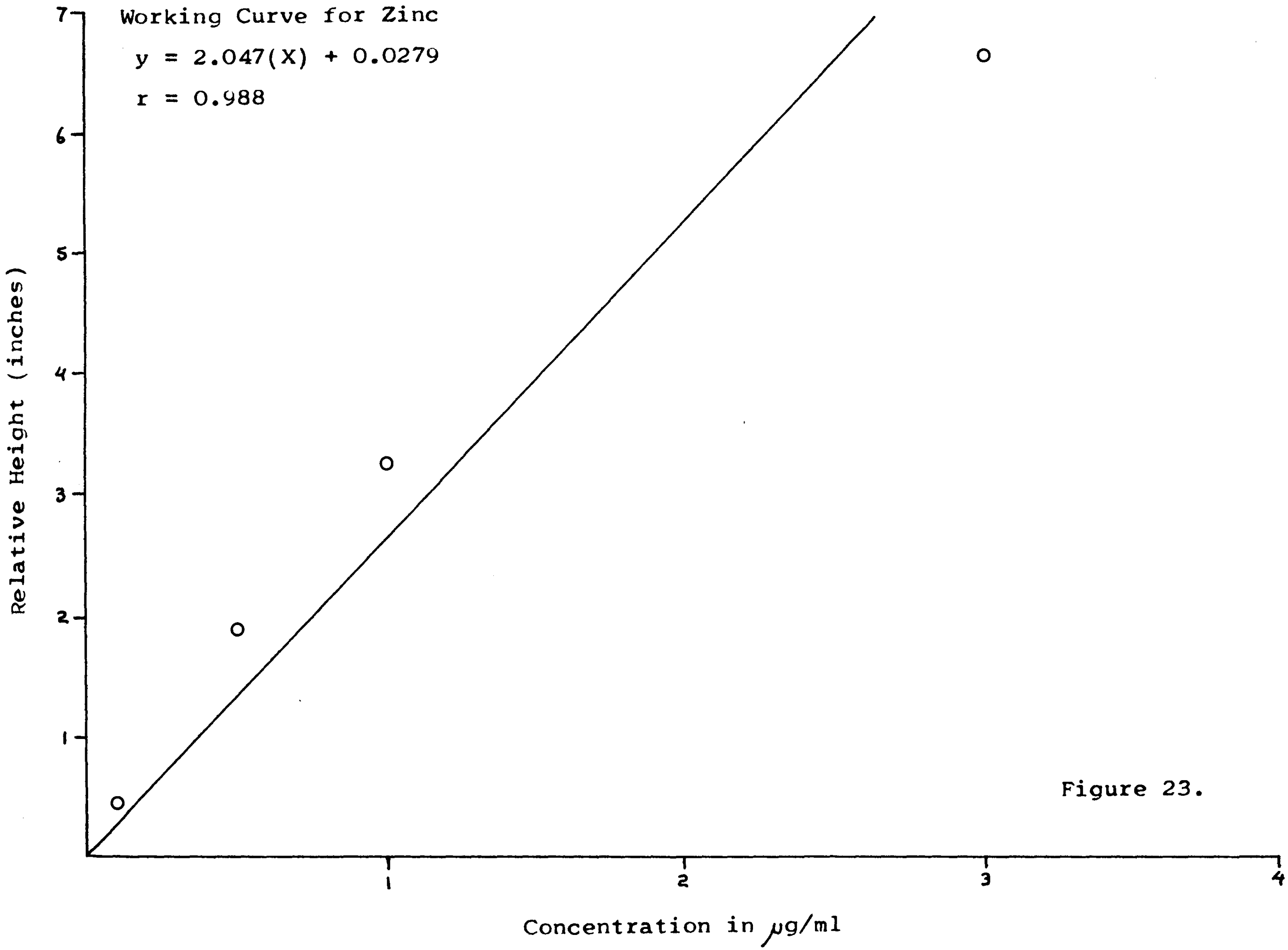

Working Curve for Zinc
y = 2.047(X) + 0.0279
r = 0.988
Relative Height (inches)
Concentration in μg/ml
1
2
3
4
5
6
7

Figure 23.

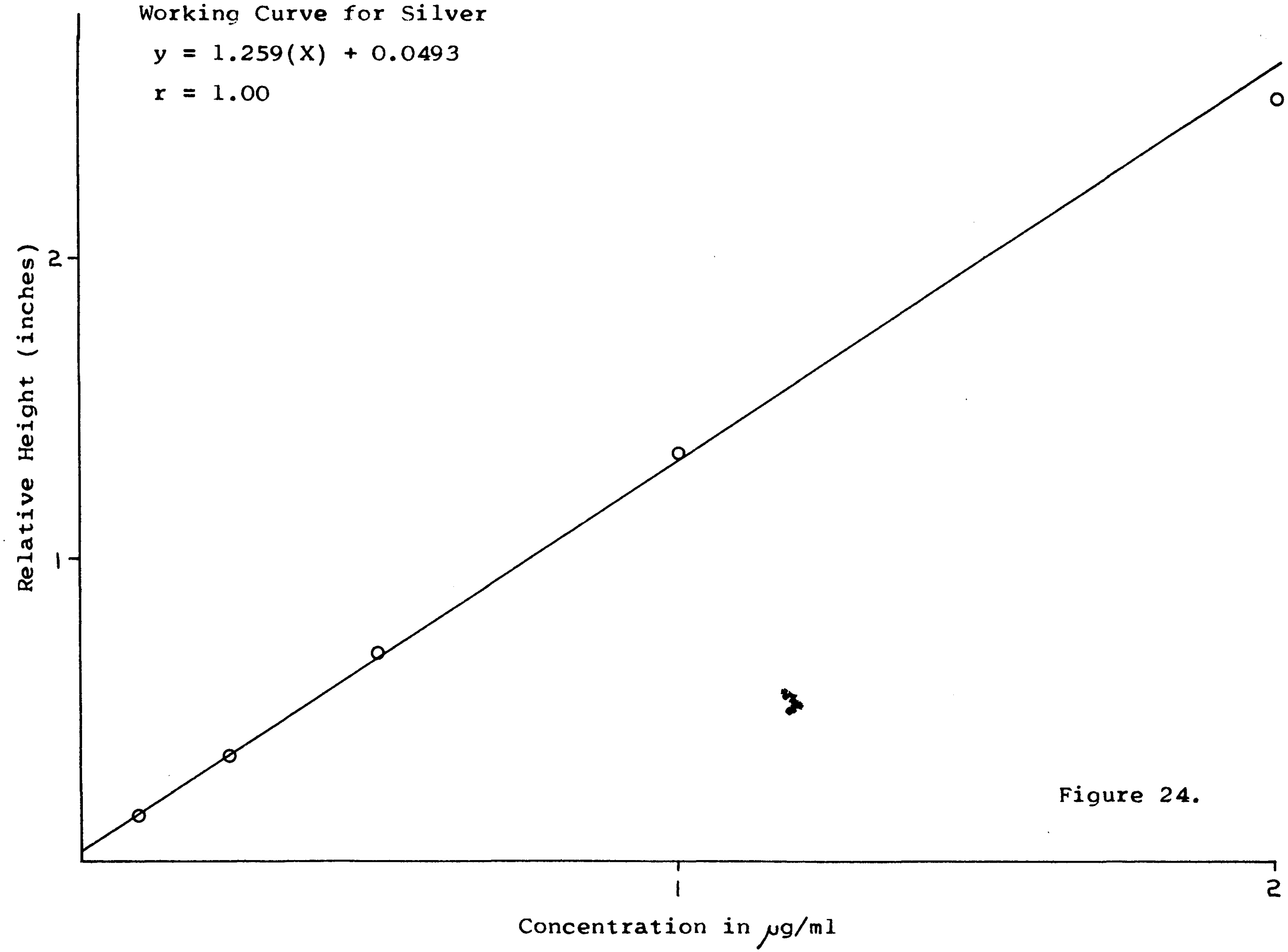
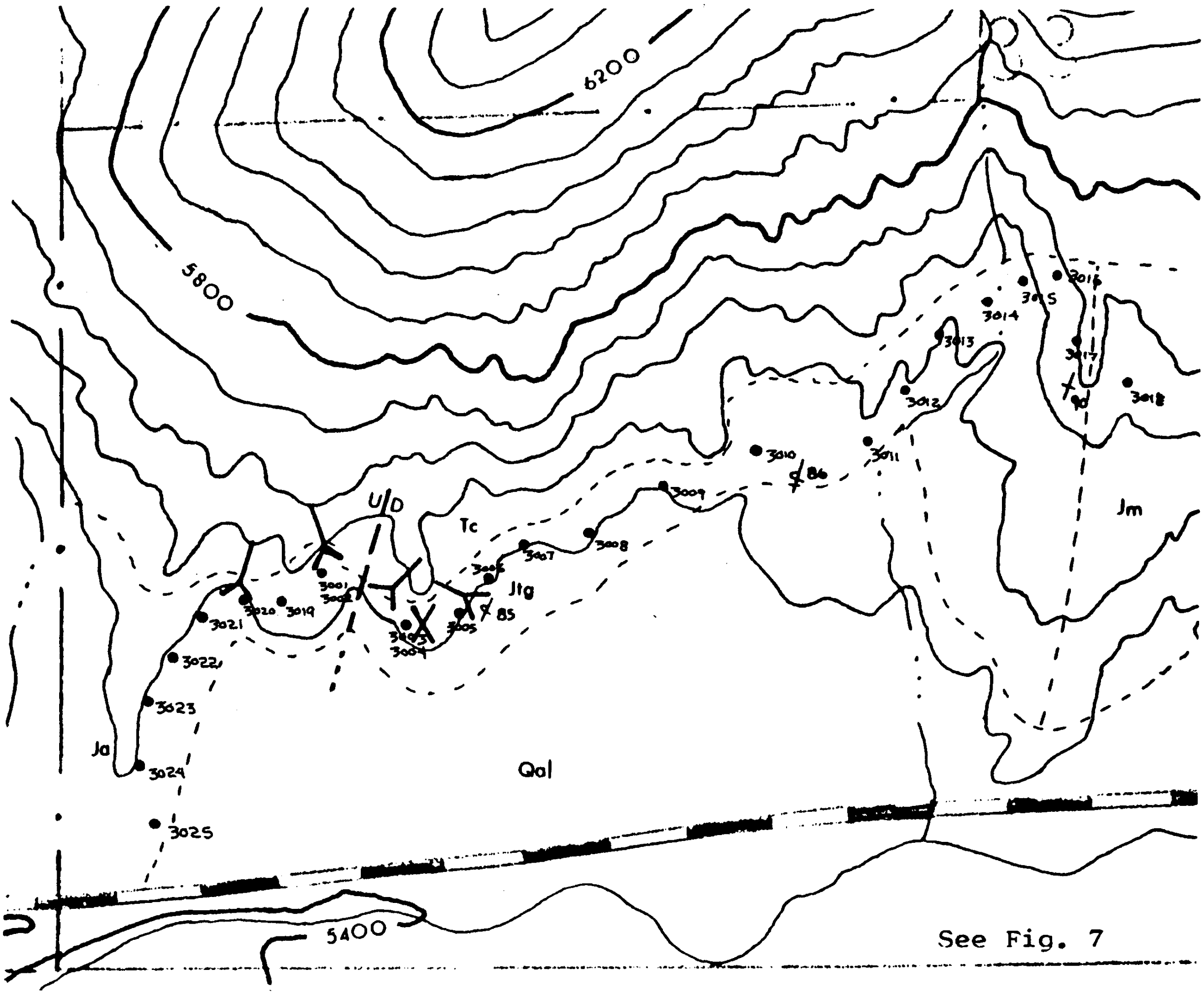

Working Curve for Silver
y = 1.259(X) + 0.0493
r = 1.00
Relative Height (inches)
2
1
Concentration in µg/ml
1
2

Figure 24.



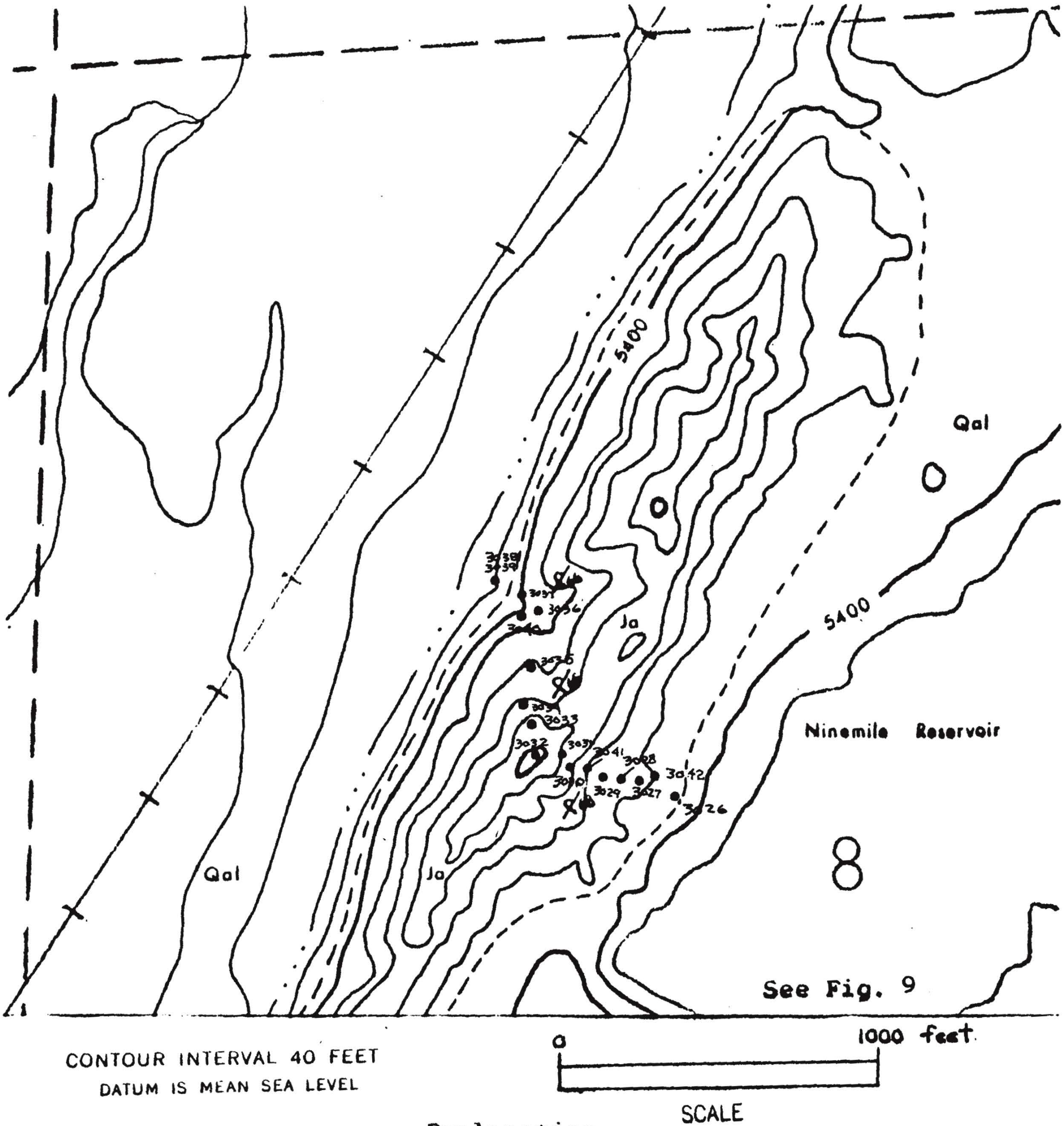
CONTOUR INTERVAL 80 FEET
DATUM IS MEAN SEA LEVEL

0 1000 feet
SCALE

Explanation

Qal	**Alluvium**
Tc	**Colton Formation**
Jm	**Morrison (?) Formation**
Jtg	**Twist Gulch Formation**
Ja	**Arapien Shale**

Figure 25. Sample locations



Explanation

Qal Alluvium

Ja Arapien Shale

Figure 26. Sample locations

Sample Preparation

The preparation of the samples for copper, lead, zinc, and silver was slightly modified after Warlow (1978). Approximately 0.5 grams of powdered sample (obtained by statistical splitting) was placed in a Teflon beaker. To this was added 10 ml of concentrated Hydrofluoric acid, 4 ml of concentrated Nitric acid, 4 ml of concentrated Hydrochloric acid and up to 10 ml of 30% v/v Hydrogen Peroxide. The latter reagent was added to destroy organic matter in the sample. The solution was heated gently to dryness, and the residue was taken into solution with hot 10% v/v Nitric acid. This solution was transferred to a 100 ml volumetric flask, allowed to cool, and then brought to volume. The solutions were stored for analysis in airtight 125 ml plastic bottles.

A small amount of unidentified white precipitate was present in most samples. It may be an organic residue, although it presisted upon addition of 30% v/v Hydrogen Peroxide.

The sample solutions were aspirated for 15 seconds. Sets of five were bracketed by blank solutions to monitor possible equipment fluctuations during the analysis. The standard solutions were aspirated at the beginning and end of each of the separate metal analyses. The results of these analyses are given in Appendix B.

APPENDIX B: ANALYTICAL RESULTS PER SAMPLE

The analytical results per sample for copper, lead, and zinc are shown in table 4. Sample concentrations for si;ver in all cases fell below the lower detection limit. Also shown on table 4 are the relative percentages of copper, lead, and zinc used in plotting the copper : lead : zinc diagram (Figure 18).

Table 4. Analytical Results per Sample

	ppm			Relative %		
Sample	Cu	Pb	Zn	Cu	Pb	Zn
3001	16	42	124	9	23	68
3002	16	67	3728	0.4	2	98
3004	21	169	289	4	35	60
3005	36	233	266	7	44	49
3006	11	111	133	4	44	52
3007	16	56	158	7	24	69
3008	21	108	123	8	43	49
3009	21	60	210	7	21	72
3010	26	88	112	12	39	49
3011	6	100	86	3	52	45
3012	11	83	72	7	50	43
3013	27	120	140	9	42	49
3014	27	141	175	8	41	51
3015	11	144	77	5	62	33
3016	11	67	81	7	42	51
3017	12	75	74	7	47	46
3018	11	90	71	6	52	41
3019	6	74	214	2	25	73
3020	11	84	223	3	26	71
3021	21	34	407	5	7	88
3022	16	90	137	7	37	56
3023	17	119	113	7	48	45
3024	16	89	118	7	40	53
3025	17	110	117	7	45	48
3026	6	87	63	4	56	40
3027	16	94	91	8	47	45
3028	11	28	92	8	21	71
3029	16	110	106	7	47	46
3030	21	100	118	9	42	49
3031	21	87	87	11	45	45
3032	11	90	99	6	46	48
3033	21	143	180	6	42	52
3034	16	106	112	7	45	48
3035	21	93	162	8	34	58
3036	6	74	76	4	47	49
3037	16	106	160	6	38	56
3038	20	128	154	7	42	51
3039	6	55	59	5	46	49
3040	11	45	53	10	41	49
3041	6	28	70	6	27	67
3042	532	92	67	77	13	10